Ontario Residential and Commercial Energy Demand Study

Informetrica Limited

and

Energy Research Group
Carleton University

Ministry
of
Energy
Ontario

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January 1978

Section One

The Residential and Commercial Sectors -
Specification and Base Period Values

Section Two

Analysis of Technical Factors Affecting
Residential Energy Consumption

Ontario

Ministry of
Energy

Queen's Park
Toronto Ontario

NOTE TO THE READER

This study is one of three studies commissioned by the Ministry on the subject of energy demand within the Province.

The other two studies are:

(1) Transportation Energy Demand Analysis, by Canadian Resourcecon Limited;

(2) Industrial Energy Demand Analysis, by Acres Consulting Services Limited.

The purpose of these studies was to critically examine the structure of energy demand within the Province, to review the possible changes that could impact on future energy use patterns and to provide a means for projecting future energy demand based on the user's own view of socio-economic and technological developments in the future. This report does not contain a forecast.

The report is in two sections. In most instances the correspondence of symbols has been maintained. One exception is in the breakout by year of construction for the housing stock.

This report is being released to aid other energy researchers. The reader is cautioned that the lack of readily available data did not allow sample calculations in the commercial sector. Specification changes may be necessary when the model is implemented. Also, there are instances where the analysis and the quality of the parameter estimates have been limited by resource or data availability. Refinements and extensions to this work are planned. The Ministry would appreciate any comments or suggestions from the reader.

Section One

The Residential and
Commercial Sectors

Specification and
Base Period Values

Final Report
Section One

For: Ontario Ministry of Energy

Date: March 25, 1977
Revised January 18, 1978

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FOREWORD

This document is part of a report on the results of an analysis of residential and commercial energy demand in Ontario. The work was conducted under a contract between the Ministry and Informetrica Limited, which was assisted by the Energy Research Group of Carleton University. The objective of the study is to improve the ability of Ministry staff to examine energy-related policy issues by allowing them to make soundly-based quantitative estimates of changes in fuel demand patterns by end use.

Michael McCracken of Informetrica Limited exercised overall direction of the project. Principal investigator for Informetrica Limited was Irving Silver, Senior Advisor. He was assisted by Paul Jacobson, Senior Economist. Principal investigators for the Energy Research Group were Professors J.T. Rogers and David Moizer and Mr. Bruce Findlay. They were assisted by Messrs. Rick Moll, Michael Swinton and A. Abdelkerim.

Executive Summary

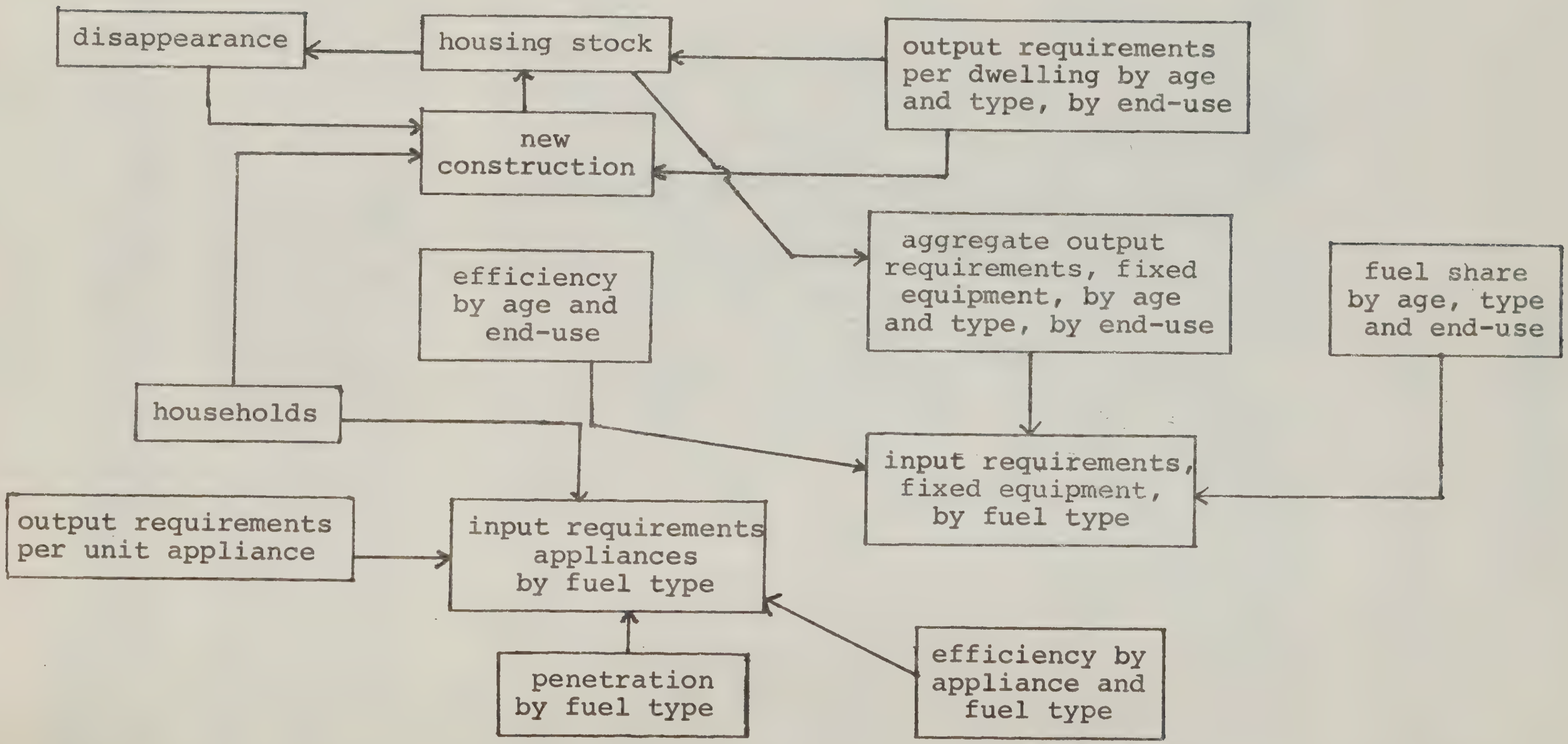
Part One: The Residential Sector

A set of identities is formulated, linking the major components of residential demand. The relationships linking these identities are represented in the following diagram. The structure reflects the importance of capital stock in the determination of changes in the demand for energy. The capital stock is itself divided into two major types: fixed equipment, which is an integral part of the dwelling unit; and appliances. This distinction is made for four reasons. First, fixed equipment is associated predominantly with space heating and water heating. These represent the great bulk of residential energy consumption and therefore require detailed treatment. Central air-conditioning is also included as a potential major end-use. On the other hand, while appliances include a large variety of specific types of equipment, they consume individually only very small fractions of total residential energy. Accordingly, individual types of appliances may be aggregated together for analysis. Second, because of the magnitude of the consumer's expenditures on space heating, it is possible that different behavioural relationships pertain to this category than for appliances, where fuel costs are in nearly all cases very small. Third, changes in fuel type are pertinent mainly to fixed equipment. Only a greatly increased relative price for electricity is likely to reduce its predominance in appliance use. The penetration of other fuels (thus far only gas) in this class of end-uses tends to be dependent upon the choice of fuel for space heating. Fourth, the installation and scrappage of fixed equipment can, for computational convenience, be linked directly with construction, aging and removal of dwellings, which are in turn linked with household formation.

Energy is not desired in and of itself as a consumer good. The demand for energy is <u>derived</u> from the demand for the services of equipment and appliances utilized with energy inputs. The framework recognizes this distinction. It traces back from the demand for the output of energy-using equipment, through the conversion efficiency of the equipment and the relative penetration of each end use by specific fuels to the consumption of each of those fuels.

The following are the major relationships which comprise the analytical framework for the residential sector. Each of these relationships may be expressed as one or several equations.

Schematic: Residential Sector (simplified)



1. The housing stock grows in response to changes in the size of the population and household formation.

2. The composition of the housing stock with respect to its heat loss characteristics depends upon the rate of new construction and demolition of older units, the regional location and structural characteristics (structure type, insulation, etc.) of new construction, and changes to the existing stock affecting heat retention and infiltration.

3. Changes in housing characteristics affecting heat loss depend upon perceived operating costs, which in turn depend upon degree-days, fuel prices and the prices of building materials (including insulation) and space heating equipment.

4. The capacity of the space heating equipment of the housing stock by fuel type depends upon degree-days, structural characteristics, the penetration of that fuel type, and the rates of growth of equipment in new housing,and of replacement and modification of equipment in the existing housing stock.

5. Penetration by fuel type depends upon the anticipated relative operating costs with the individual fuels, given the characteristics of the housing stock. Relative operating costs depend upon relative fuel prices adjusted for availability and securing of supply, conversion efficiencies and capital costs.

6. The conversion efficiency of installed equipment depends upon the rate of technological innovation and maintenance.

7. Changes in the stock, i.e., number of units, of appliances depend upon the growth in number of households and units per household.

8. Changes in the output of the appliance stock per unit depend upon income and family characteristics of the households, the prices of appliances, and changes in appliance technology.

9. The conversion efficiency of appliances depends upon the rate of technological innovation.

10. Fuel consumption by type is the resultant of output, penetration and conversion efficiency.

Part Two: The Commercial Sector

The analytical framework for the commercial sector is formally very similar to that for the residential sector.

The decision-making unit, instead of the household, is the commercial establishment (including operations of government). The long-run determinants of commercial energy demand are related to the stock of commercial physical capital, including both buildings and other facilities such as the street lighting system, and the equipment occupying such facilities.

Analogous to the distinction between equipment and appliances in the residential sector is that between fixed (or installed) equipment, primarily space conditioning and motive power, and use-dependent equipment (copying machinery, etc.). In the residential sector, households vary in the extent to which they possess individual items from the full possible complement of appliances. In the commercial sector, the problems of accounting for differences in consumption patterns among sectors is more complex. For personal-service industries, for instance, cooking equipment (in restaurants) may be important while for retail trade refrigeration equipment may play the same role, while cooking equipment is insignificant, etc. To build up aggregate estimates of moveable equipment energy consumption requirements from detailed equipment distributions by industry would be an enormous task; consequently, considerable simplification will be required. The distribution of types of activity by sector is used, however, as a basis for estimating equipment requirements and subsequently energy demand.

An important difference from the analysis of the residential sector is in the method of determining output requirements for fixed equipment. Particularly for commercial structures built since about 1950, energy requirements for cooling are about equal to those for heating. The capacity of installed equipment depends primarily upon the configuration of the building, which depends upon the nature of the activity carried on in the particular sector and upon the economic density consistent with land and building costs. Climatic conditions are thought to play only a minor role.

The following are the major relationships which comprise the analytical framework for the commercial sector.

1. The stock of commercial structures (in terms of floor space of buildings, miles of urban street lighted, etc.) grows in response to changes in levels of production in the commercial sector.

2. Changes in the characteristics of structures by sector and region depend upon urbanization and changes in technology.

3. Capacity of installed equipment by sector and region depends upon the growth of floor space and of the ratio of energy output requirements to floor space in new and existing building.

4. Installed capacity per square foot by fuel type within each sector and region depends upon the total capacity, the rate of new construction, penetration by each fuel type in each type of structure, new and (by retro-fitting) existing.

5. Actual energy demand per square foot depends upon utilization of fixed equipment in the various types of structures and their installed capacities.

6. The demand for energy for process equipment by type of fuel used depends upon the growth of production in the individual sectors, the rates of output of equipment relative to production in each sector and the penetration by fuel type.

Unlike the residential sector, it has not been possible to implement the commercial framework in the form of an illustrative calculation with the time and resources available. What has been learned in the attempt is summarized in a set of recommendations for future work.

PART ONE:

THE RESIDENTIAL SECTOR

Specification of the Structure

Step 1: The stock of housing units is survived from period to period by subtracting disappearances.

$$(1)\quad HS_{i,j+1,1} = HS_{ij1,t-1}*(1-DR_{ij1})$$

where

$HS_{i,j+1,1}$ = number of housing units of type i, age j + 1, and region 1

$HS_{ij1,t-1}$ = number of housing units, etc. in previous period

DR_{ij1} = disappearance rate of housing

Comments

1. This equation allows us to calculate the distribution of housing units by type of structure and region. This distribution will determine, jointly with other variables, the number of units and characteristics of fuel-using devices and hence the technical capacity of households to satisfy their demand for energy in each period.

2. The age-structure of the housing stock should be as finely disaggregated as possible for this step in order to reflect accurately the variation in specific rates of disappearance which might be assumed to prevail up to about twenty-five years. Subsequently, less disaggregation by age may be carried. For the purpose of reflecting changes in construction characteristics resulting from changes in building technology or codes which influence heat-loss characteristics, for instance, a simple weighted average of the characteristics of new and surviving housing may be employed.

3. Changes in numbers of units of each category of the standing stock may result from conversions of structures to/from other uses, as well as by demolition. The disappearance rate is therefore a net figure and need not be positive, although it usually is, and will be so assumed for the present exposition. Little is known about the causes of variation in the disappearance rate or its components over time. Consequently,it is most likely that projections would employ historic rates or trends in such rates.

4. Since there is an open-ended age category, equation (1) must be modified for that category as follows:

$$\text{(1a)}\quad HS_{i,jo,l} = HS_{i,jo-1,l,t-1} * (1-DR_{i,jo-1,l}) + HS_{i,jo,l,t-1} * (1 - DR_{i,jo,l})$$

where jo represents the open-ended category.

Alternative methods of projection

1. Extrapolation

The average rate of disappearance derived for the period 1961-1971 is maintained over the forecast period.

2. Disappearance rate a function of population growth

We assume that population growth modified for rate of urbanization, affects the rate at which existing units are removed from the stock for replacement by new housing or non-residential use. The rate of disappearance is made a function of structure type, age and population or household growth in the relevant housing market. Forecasts of population or households by region are then employed to project disappearance rates.

3. Disappearance rate a function of energy cost

We assume that the probability of scrappage or conversion of housing structures depends upon capitalized future rents minus costs, including fuel costs. The same procedure would be employed as in 2, but the cost of fuel by class of structure-age-region would be included as a determinant of the disappearance rate.

Calculations of base period values

In order to obtain the projected distributions of the stock by structure type and 5-year age groups, the 1971 distribution of the occupied housing stock by period of construction, as reported in the Census, is revised.

Occupied dwellings by type of structure are inflated by a vacancy factor representing average rates observed by experience and commonly found in the real estate and housing literature. In all subsequent steps, the number of housing units in each class includes both occupied and vacant units. For Ontario these rates are:

single-detached	2 percent[1]
single-attached	3 percent
row	3 percent
large multi-unit	4 percent

The results of these calculations are shown in the following tables.

The initial age distribution, published in the 1971 Census, is recalculated by five-year groupings up to an age of 25 years, for ease of projection, which is carried out in five-year increments.

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[1] The 2 percent figure allows for second homes, used primarily for recreation and vacant during nearly all of the heating season; however, the presumed lower energy requirements for this portion of the stock are not reflected in the subsequent calculations.

Starting Distribution of Occupied Dwellings by Age and Type, Ontario, 1971

Year	Before 1921	1921-1945	1946-1960	1961-1965	1966-1969	1970-1971[1]	
Age (years)	52+	27-51	12-26	7-11	3-6	1-2	Total
Total (incl. mobiles)	509635	376106	716605	284861	264832	73441	2,225,480
	22.9%	16.9%	32.2%	12.8%	11.9%	3.3%	(100%)
Single detached (incl. mobiles)	310588	244623	523603	149797	116814	28860	1,374,285
	22.6%	17.8%	38.1%	10.9%	8.5%	2.1%	(100%)
Single attached (doubles & duplexes)	79575	44562	43827	30850	34278	11753	244,845
	32.5%	18.2%	17.9%	12.6%	14.0%	4.8%	(100%)
Row	29593	16572	16299	11473	12748	4371	91,055
	32.5%	18.2%	17.9%	12.6%	14.0%	4.8%	(100%)
Apts.	100998	74718	126763	89146	96875	26795	515,295
	19.6%	14.5%	24.6%	17.3%	18.8%	5.2%	(100%)

Assume that all types of single attached houses have the same age distribution, as calculated from 93-738, Table 29.

Source: 93-738, Table 29
93-727, Table 4

[1]Includes first five months of 1971.

Revised Distribution of Occupied Dwellings by Age and Type, Ontario, 1971
Using 5-year Age Classes

Year	Before 1947	1947-1951	1952-1956	1957-1961	1962-1966	1967-1971	Total
Age (years)	25+	20-24	15-19	10-14	5-9	0-4	
Total (incl. mobiles)	932476	233675	233675	244803	298214	273734	2,225,480
	41.9%	10.5%	10.5%	11.0%	13.4%	12.3%	(100%)
Single detached (incl. mobiles)	589568	171786	171786	167663	149797	115440	1,374,285
	42.9%	12.5%	12.5%	12.2%	10.9%	8.4%	
Single attached (doubles & duplexes)	127075	14691	14691	17874	33054	37461	244,845
	51.9%	6.0%	6.0%	7.3%	13.5%	15.3%	(100%)
Row	47258	5463	5463	6647	12292	13931	91,055
	51.9%	6.0%	6.0%	7.3%	13.5%	15.3%	(100%)
Apts.	183960	41224	41224	51014	96360	99452	515,295
	35.7%	8.0%	8.0%	9.9%	18.7%	19.3%	(100%)

Derived from preceding table by interpolation.

Final Distribution of Dwellings
Inflation for vacancies of the number of dwellings, Ontario, by age and type, in the base year 1971

Age (years)

Structure Type	25+	20-24	15-19	10-14	5-9	0-4	Total
Total (incl. mobiles)	972240	238854	238854	249327	299714	274113	2273102
Single detached (incl. mobiles)	601359	175222	175222	171016	152793	117749	1393361
Single attached (doubles & duplexes)	130887	15132	15132	18410	34046	38585	252192
Row	48676	5627	5627	6846	12661	14349	93786
Apts.	191318	42873	42873	53055	100214	103430	533763

Step 2: The number of units of new residential construction by type and region is determined by net new household formation plus requirements for replacement of units lost through disappearance.

$$(2) \quad HS_{i,j=1,l} = DHO_{il} + \sum_j HS_{ijl,t-1} * DR_{ijl}$$

where

$HS_{i,j=1,l}$ = number of housing units of type i constructed in region l during the current period

DHO_{il} = net change in households occupying housing of type i in region l

Comments

1. This equation is an identity, except for adjustments for vacancies which are the difference between total households and total housing units. If we assume that unoccupied dwellings represent a negligible amount of energy consumption, we can deal only with the number of occupied units (= number of households) and (2) becomes an exact identity. On the other hand, if we wish to account for energy consumption by vacant units, we must add a term to represent change in vacancies in the housing type i, etc. The term HS then refers to all units, occupied or vacant. This is the procedure which was employed in Step 1.

2. This equation represents one of the major "hooks" in the structure whereby alternative assumptions about the rate and pattern of provincial growth may be introduced. Various assumptions about demographic rates, household formation rates, urbanization and housing demand may be used to calculate variations in the determinants of new construction, i.e., household growth and distribution,and rates of demolition. The equation also makes it possible to introduce assumptions about the effects of energy costs on those determinants. It might be assumed, e.g., that costs of homeownership,relative to renting,would increase by some amount due to differential increases in heating and other energy costs. The amount of these cost increases would be calculated using the analytic structure and assumptions about fuel prices. These calculated costs could then be combined with other projections of housing costs to predict their influence on the distribution of households by structure type. Such predictions might be made by means of formal models, such as the one developed by TEIGA ("An Econometric Study of Demand and Supply for Housing in Ontario") or by judgemental estimates.

Alternative methods of projection

1. Existing studies

Use existing projections of net household change and type of housing occupied, such as the figures included in "Housing in Ontario" produced by the CMHC Regional Economist's Office (1975).

2. Housing distribution a function of income, demographic, urbanization characteristics

The distribution of households among housing types is made a function of income, family characteristics, and degree of urbanization (representing relative land prices in different regions).

Calculation of base period values

In 1971 the shares of housing units by structure type in the total stock for the province were as follows:

Structure Type	Percent
single detached	61.3
single attached	11.1
row	4.1
apartment	23.5

These shares are consistent with the vacancy assumptions introduced in Step 1.

Step 3: The output energy requirement for space heating per dwelling is calculated from the "equivalent degree day method".

(3) $OH_{ijlm} = K_{ijlm}*24*EDD_{ijlm}$

where

OH_{ijlm} = average output heating energy requirement (BTU/dwelling yr) by dwelling type i, age j, regional location l and heat-loss class m.

K_{ijlm} = heat loss factor (BTU/HR ^{o}F) by dwelling type i, age j regional location l and heat-loss class m.

24 = hours in the day

EDD_{ijlm} = equivalent degree days as a function of type i, age j region l and heat-loss class m.

Comments

1. This equation, is derived in the Second Section of this Report ("Analysis of Technical Factors ....") and is employed to introduce changes in structural characteristics - insulation, square footage, age - within each structure type and region affecting heating requirements via the calculation of "K". A variety of assumptions with respect to investment in energy-saving structural features in new construction and by retro-fitting may be examined in this way.

2. Output heating energy requirement (OH) is defined as the rate of usable heat delivered by the heating system. Usable heat excludes flue losses.

3. The variation in the structural characteristics of the housing stock determines the classification of K by i, j, l and m. The principal factors which determine heat loss from a building include:

(1) the insulation used;

(2) the area of each building component analyzed (e.g., ceiling, wall, etc.);

and (3) the infiltration rate.

Each factor varies according to the type of dwelling i, period of construction j and regional location l. The subscript m is included because, within each class defined by the other subscripts, there are significant differences in the heat loss factor, at least in the base period, between electrically-heated and non-electrically-heated housing, due to the substantially greater insulation levels in the former. This same index could be used to distinguish other classes, e.g., solar-heated units.

4. The age index allows us to distinguish housing constructed at different times during the base and forecast periods. It may be assumed that, as a result of prevailing concern about rising energy costs and shortages of specific

fuels, housing to be constructed in the future will differ from existing housing not only in its heat-loss characteristics but also in the costs involved in altering heat-loss. For instance, if solar heating is treated as a heat-gain (rather than as heating equipment with zero fuel price), then its installation in an existing house would reduce net heat-loss. If future housing is designed (at some increment in initial construction cost) to be converted to supplemental solar heating without major structural changes, the speed and extent of reduction in heat-loss in response to further price increases may differ significantly (via solar heating) from that in housing surviving from the present (via improved insulation, etc.).

5. Because of the predominance of space heating as a source of residential energy demand, the sensitivity of total residential energy demand to variations in the input variables of equations (2) and (3) is likely to be far greater than its sensitivity to proportional perturbations of variables in other parts of the structure.

6. The regional subscript on K indicates variation due to fuel-saving measures in the form of structural features, as a response to variations in degree-days. Such measures would include principally differences in insulation of the ceiling and walls.

Alternative methods of projection

Two sets of assumptions are made - one pertaining to new construction, the other to the existing stock.

1. New construction: extrapolation

It is assumed that changes in average heat-loss factor result entirely from change in the composition of the new construction in terms of structure type and regional location. The heat-loss rate computed for each structure type in the most recent available year is maintained over the forecast period.

2. New construction: specific configurations

It is assumed that requirements included in existing or proposed building codes will be the effective norm for all construction. Heat-loss factors in the forecast period are computed on the basis of the associated specific architectural features. Assumptions about the impact of introducing various structural features other than those mandated by the codes may also be examined in this way.

3. New construction: heat-loss rate a function of operating costs

Households could be assumed to minimize the portion of their residential operating costs attributable to energy consumption, subject to the prior choice of housing type and location, and some minimum comfort level. Additional savings on space-heating cost due to investment in structural features such as insulation would just equal reduction in costs due to investment of other forms, especially more efficient fuel type/equipment combinations, i.e., marginal returns would be equal for all

forms of investment. This approach would desirably be based upon information on relative efficiencies of fuel-saving investment per dollar.

4. Existing housing: extrapolation

The technique is the same as the one applied to new construction in Alternative 1. The assumption is that the structural characteristics affecting heat-loss are not altered in existing housing under any circumstances, i.e., there is no retro-fitting during the projection period.

5. Existing housing: specific configurations

By comparing current and proposed codes with the characteristics of existing housing, estimates could be made of the effect upon heat-loss factors of improving sub-standard units to the prescribed level or a judgementally-derived feasible level at a specified rate over time. As in Alternative 2, assumptions about penetration by specific fuel-saving measures could also be introduced in this way.

Calculation of base period values

Average space heating requirement

Delivered heat rates (BTU/dwelling-year) have been calculated for typical dwellings by:

- structure type
- region
- type of heating fuel (electric, non-electric)
- period of construction (pre-1966, 1966-71, 1972-76)

Regional variations in ambient design temperature have been reflected in the specifications of the typical structures (see Second Section). Heat-loss rates were calculated separately for electrically-heated and non-electrically heated units (represented by the index "m") because of the substantial differences in insulation values in the base period. Detailed assumptions as to the physical characteristics of the structures affecting heat loss are presented in the Second Section.

To obtain an average figure for heat-loss per dwelling for the province, the rates for the individual region-structure type-age categories are aggregated across regions, weighting each rate by the proportion of dwellings in the region.

Average Heat Requirement, 1976
(Output BTUx10^6)

Age Group (Year)	Single Detached	Single Attached	Row	Apartment
Non-electrically heated				
0-4	94.7	62.6	37.6	15.9
5-9	123.9	81.2	47.1	19.6
10-14	136.6	104.8	50.8	20.6
15-19	136.6	104.8	50.8	20.6
20-24	136.6	104.8	50.8	20.6
25+	136.6	104.8	50.8	20.6
Electrically Heated				
0-4	73.8	47.0	26.1	8.5
5-9	82.8	53.3	30.1	11.3
10-14	83.3	53.6	30.2	11.5
15-19	83.3	53.6	30.2	11.5
20-24	83.3	53.6	30.2	11.5
25+	83.3	53.6	30.2	11.5

<u>Step 4</u>: The total output energy requirement for heating by type of dwelling, age, regional location and fuel type, is calculated from:

$$(4) \quad OHH_{ijln} = \sum_{m} OH_{ijlm} * HS_{ijlm} * PNH_{ijlmn}$$

where

OHH_{ijln} = Total output energy requirements for space heating (BTUs/dwelling-yr.) by housing type i, region l, age j and fuel type n.

PNH_{ijlmn} = Penetration, i.e., the percentage of dwellings in i, j, l, m which use fuel type n for space heating.

<u>Comments</u>

1. This equation allows us to introduce assumptions about the relative contribution of various types of fuel to space heating and of substitution among fuels in response to price or supply constraints.

2. The item PNH_{ijlmn}, penetration as a proportion of dwellings by type, age, region, heat-loss class and fuel type, needs to be distinguished from "fuel share". The latter may be expressed in output terms (= OHH_n as a share of total OHH) or in input terms (= fuel consumption by type as a share of total fuel consumption). In the base period calculation, heat-loss class is identical with electrical and non-electrical space heating; therefore, for the former class, penetration of electricity = 1.0.

Alternative methods of projection

1. Maintenance of existing rates

It is assumed that there is no substitution among fuel types in response to changes in relative prices and that supply constraints, if any, will not be such as to disturb the existing penetration rates. Holding penetration rates constant in the projection, would allow the effects of investment in heat-loss resistance, calculated in Step 3, to be examined independently, if the degree-day factor in Step 3 is also maintained at the reference level.

2. Extrapolation of penetration rates

The extrapolation of penetration rates from historical trends would also be consistent with an absence of response to price, and an assumption that past determinants of market share will continue to change at the same rates.

3. Extrapolation of penetration rates with saturation reflecting assumed prices

On the basis of assumptions about future levels of fuel price and of technological and supply changes, long-run market shares may be derived judgementally or by reference to econometric studies. The approach to these long-run levels could be formulated as some type of growth curve.

4. Econometric estimation of fuel choice

The relation of penetration rates to fuel prices could be derived by econometric estimation. Using this approach, we might, for instance, examine fuel shares in different localities with differing degree-day levels and fuel prices from which

the response in fuel consumption to price could be estimated. This approach would enable us to examine a number of specific propositions about behaviour which are consistent with the theory of consumer budget allocation. The difficulty is with regionally-specific supply constraints and prices which are both regulated and historically at much lower levels than can be expected in future. It would, therefore, be difficult to estimate the parameters either of true long-run demand or of the dynamic adjustment process.

Calculation of base period values

Penetration

The penetration of the various types of fuel for space heating in 1976, in terms of proportion of housing units by type and period of construction is:

Housing Type	Electricity	Oil	Gas	Other
Single detached				
pre-1966	.026	.613	.325	.036
1966-71	.180	.348	.458	.014
1972-76	.224	.170	.605	.000
Single attached				
Pre-1966	.029	.507	.452	.012
1966-71	.161	.159	.677	.003
1972-76	.281	.158	.561	.000
Row				
Pre-1966	.029	.507	.452	.012
1966-71	.161	.159	.677	.003
1972-76	.281	.158	.561	.000
Apartment				
Pre-1966	.065	.553	.349	.033
1966-71	.256	.272	.460	.012
1972-76	.217	.010	.765	.000

Sources: Constructed from Ontario Hydro Energy Application Survey, Special Tabulations from the 1971 Census, and from electrical inspection data for subsequent years. Single attached and row housing are grouped in an "other" class; hence, their distributions are assumed equal.

Step 5: The output of water heating equipment by fuel type is calculated as the product of output per dwelling unit, number of dwellings and penetration by fuel type.

(5) $OHW_{ijln} = OW_{il} * HS_{ijl} * PNW_{ijln}$

where:

OHW_{ijln} = output of water heating equipment by housing type i, age j, region l, and fuel type n

OW_{il} = output per dwelling by i, l

PNW_{ijln} = penetration (share of dwellings) by i, j, l, n

Comments

1. The term OW_{il} can be made to reflect changes in installed capacity due to changes in income, family size and "consumer technology" such as washable vs. non-washable clothing, ownership of dishwashing machinery, etc. It can also be used to represent the possibility of energy savings through reduction of tank temperature. Other measures to reduce energy requirements would involve efficiency changes which are to be treated in Step 7.

2. The term PNW_{ijln} embodies changes in the equipment due to changes in relative fuel costs, constrained by fuel used by the furnace or range and regional availability of fuels. Water heating may increasingly involve more than one type of fuel within a dwelling, if, e.g., point-of-use heaters become more widespread.

Alternative methods of projection

1. Maintenance of existing rates

Output per unit and penetration rates would be held constant on the assumption that neither the technical characteristics, investment in equipment nor intensity of use would be altered by future price changes, technical improvements or changes in taste.

2. Extrapolation of rates

The simplest method for projecting growth of this end use would be to extend past rates of change per capita, insofar as historical information is available to allow measurement over time.

3. Output per dwelling: specific technical changes

Specific changes in the physical characteristics of water heaters, such as greater tank insulation, new types of systems, etc., can be introduced in terms of their output capacities and rate of introduction in new housing and by replacement or supplementation of units in existing housing.

3. Output per dwelling: demand equations and growth curves

The simplest way of projecting output per dwelling so as to incorporate economic variables explicitly would be to regress calculated output per dwelling in the base period upon various household characteristics such as income and family size. This could be accomplished with the HIFE microdata file. Penetration could be similarly derived by the construction of logistic curves relating this variable to output per dwelling and the fuel share of central heating.

Calculation of base period values

Output per dwelling

Hot water consumption is related to number of persons in the household. Output is related to quantity of hot water consumed and standard operating temperatures. Output by housing type is calculated by employing Census figures on household size in each type. See Section Two for a detailed discussion.

$BTU \times 10^6$

Period of Construction	Single Detached	Single Attached	Row	Apt.
pre-1966	14.56	15.35	10.58	9.14
1966-71	14.56	15.35	10.58	9.14
1972-76	14.56	15.35	10.58	9.14

Penetration

The penetration of water heating equipment by fuel and structure type in the base period is as follows:

pre-1966	Single Detached	Single Attached	Row	Apt.
Electric	.425	.425	.425	.425
Gas	.560	.560	.560	.575
Other	.015	.015	.015	.000
1966-71				
Electric	.425	.425	.425	.300
Gas	.560	.560	.560	.700
Other	.015	.015	.015	.000
1972-76				
Electric	.437	.437	.437	.250
Gas	.560	.560	.560	.750
Other	.003	.003	.003	.000

Source: Constructed from unpublished Ontario Hydro figures.

Step 6: The output of central air-conditioners is computed as the product of output per dwelling, number of dwellings and penetration.

(6) $OHAC_{ijln} = \sum_{m} OHA_{ijlmn} * HS_{ijlm} * PHA_{ijlmn}$

where:

$OHAC_{ijln}$ = output of central air cooling equipment

OHA_{ijlmn} = output per centrally-cooled dwelling

PHA_{ijlmn} = penetration (share of all dwellings)

Comments

1. The incidence of central air-cooling systems is presently very low. It is included as a distinct end-use, however, because it is anticipated that future penetration, combined with its potential high level of energy consumption per unit may make it a major source of energy demand in the residential sector.

2. The subscript m represents heat-loss category.

3. While the subscript n is introduced to allow for the introduction of other fuel types, the only significant penetration during the base period has been by electricity.

Alternative methods of projection

1. Saturation analysis

Because of the low level of penetration in the base period, trend extrapolation or demand analysis based upon the existing distribution of units is liable to be a poor basis for forecasting. A method which would tie ultimate penetration to income level, structure type and region using judgemental parameters would be most appropriate. The method should allow rates of change in these population and housing variables to be employed in calculating penetration over time.

Calculation of base period values

Output per dwelling

Air conditioning requirements are determined by calculating specific values by structure type, period of construction, region and heat-loss class for solar transmission and solar radiation cooling loads. Heat-loss class is identified by type of fuel used for central heating, i.e., electric or non-electric. The base-period values of output per dwelling are as follows:

Air-conditioning Requirements

(Output BTUx10^6)

Period of Construction	Single Detached	Single Attached	Row	Apartment
Non-electrically Heated				
Pre-1966	8.002	5.699	4.200	2.403
1966-71	7.214	5.206	3.819	2.291
1972-76	6.382	4.656	3.458	2.009
Electrically Heated				
Pre-1966	5.980	4.353	3.277	1.879
1966-71	6.011	4.362	3.286	1.893
1972-76	5.411	3.980	2.978	1.710

Penetration

The penetration of air conditioning, in terms of proportion of dwellings is taken as .047. This figure is shown in the Ontario Hydro Energy Application Survey for 1974. Due to lack of sufficient data, no calculation by structure type or other disaggregation has been attempted.

Step 7: The output of appliances by structure and fuel type is calculated as the product of the appliance stock, average output per appliance, and penetration.

(7) $OA_{inp} = HS_i * OAP_{inp} * PNA_{inp}$

where:

OA_{inp} = output of appliances

OAP_{in} = average output per appliance unit p

PNA_{inp} = penetration of appliance p (units/dwelling)

Comments

1. Average output and penetration are probably not independent. Appliances tend to be acquired by the household in a particular order. In addition, some types of appliances, e.g., microwave ovens, may be well below their ultimate penetration levels. Appliances which may be expected to show a relatively large increase in penetration may be relatively more or less energy-intensive than those which have reached saturation level during the base period.

2. While there are a large number of individual appliance types, they fall into two classes with respect to penetration and fuel type. Some appliances have 100 percent penetration and can be expected to remain at this level during the forecast period, e.g., lighting. Others are still

increasing in penetration and may not achieve 100% during the forecast period. A large proportion of appliances are electric, and may be expected to remain so. For others, fuel share may depend upon relative prices, type of fuel used in central heating, and other influences.

Alternative methods of projection

1. Maintenance of existing rates

Average output per unit, penetration rates and utilization factors would be held constant on the assumption that neither the technical characteristics, investment in appliances nor intensity of use would be altered by future price changes, technical improvements or changes in taste.

2. Extrapolation of rates

The simplest method for projecting growth of this end use would be to extend past rates of change of output per capita, since historical information is available to allow measurement over time.

3. Output per dwelling: specific technical changes

Specific changes in the physical characteristics of appliances such as more automatic features, can be introduced in terms of their output capacities and rate of introduction in new households and by replacement or supplementation of units in existing households.

4. Output per dwelling: demand equations and growth curves

The simplest way of projecting output per dwelling so as to incorporate economic variables explicitly would be to regress calculated output of all appliances per dwelling in the base period upon various household characteristics such as income and family size. This could be accomplished with the HIFE file. Penetration could be derived by the construction of logistic curves relating this variable to output and the fuel share of central heating.

Calculation of base period values

For purposes of analysis, appliances were classified into four groups.

1.	non-cooking:	100 percent electric; 100 percent penetration
2.	non-cooking:	100 percent electric; less than 100 percent penetration
3.	cooking:	100 percent penetration; less than 100 percent electric
4.	clothes dryers:	less than 100 percent penetration; less than 100 percent electric

The reason for separating cooking and clothes drying appliances is to allow for the dependence of the fuel share with which they are associated upon the type of fuel used for central heating. This dependency was not actually incorporated in the illustrative calculation.

Output per Appliance Type

(Output BTUx10^6)

Group 1 (100% electric, 100% penetration)

Lighting	0.13
Refrigerator/Freezer	4.63
Radio-TV	2.05
	6.81

Group 2 (100% electric, less than 100% penetration)

Clothes Washer	0.28
Dishwasher	0.74
Room Air conditioner	2.05
Other	3.07

Penetration (%)

	Single Detached	Single Attached	Row	Apartment
Clothes Washer	94	94	94	95*
Dishwasher	11	6	6	3
Room Air conditioner	16	16	16	16
Other	60	60	60	60
Weighted Output BTU By Housing Type	2.514	2.477	2.477	2.318

Group 3 (less than 100% electric, 100% penetration)

Cooking Stove 2.05

Fuel Share

	Gas	Electric	Other
1971	.136	.821	.043
1974	.114	.863	.023

Group 4 (less than 100% electric, less than 100% penetration)

Clothes Dryer 1.31

Penetration (%)

	Single Detached	Single Attached	Row	Apartment
Clothes Dryer	54.4	38.4	38.4	14.3*
Weighted Output BTU By Housing Type	.713	.503	.503	.187

Fuel Share

	Gas	Electric	Other
Clothes Dryer	.109	.891	.000

* The concept of "penetration" of clothes washers and dryers in apartments should reflect the provision of "utility rooms". There are likely fewer appliances per household, but the intensity of use is likely much higher. A more detailed study is required here; the numbers in the example are not likely to be accurate.

Step 8: Calculate fuel consumption by structure type, fuel type and region for fixed equipment and appliances as the sum of outputs divided by their respective efficiencies.

$$(8) \quad FCONE_{in} = OHH_{in}/EH_{in} + OHW_{in}/EW_{in} + OHAC_{in}/EA_{in} + OA_{inp}/EAP_{inp}$$

where:

$FCONE_{in}$ = fuel consumption by fixed equipment

EH_{in} = conversion efficiency of space heating equipment

EW_{in} = conversion efficiency of water heating equipment

EA_{in} = conversion efficiency of air cooling equipment

EAP_{inp} = conversion efficiency of appliances

Comments

1. By treating distinctly the determinants of energy demand and the efficiency of equipment in satisfying the actual level of consumption, we are able to examine changes in fuel consumption stemming from each of the two sources. A fuel-saving measure such as closing off and reducing heating in unused rooms, for instance, would be treated as a reduction in demand. It would be entered in the analysis via adjustments to the term OH, average heating requirements, calculated in Step 3. Higher levels of boiler maintenance and other such measures would be entered via the efficiency factors in the denominators of (8), however.

2. The conversion efficiency factors are the ratios of net usable energy output to total energy input. All forms of heat loss/gain from/to the specific end use are subtracted from total energy input to obtain usable energy. Two components of efficiency may be considered. Fuel has associated with it some potential output in the form of heat or mechanical work. Some part of this potential is not available for the end-use because of incomplete combustion, i.e., the fuel lost in the form of gases. The second type of leakage relates to application. This component involves energy transmitted in a form which is not applicable to the intended end use. Heat loss up the flue for space and water heating systems is the best known and currently the most significant example. There are equivalent sources of application inefficiency in these and other end uses, however. Thus, the efficiency of electricity is frequently cited as 1.0 since there is no heat lost up the flue or by incomplete combustion, as with fossil fuels; but in water heating, for instance, it has been estimated that more than 20% of electrical energy is lost through the tank surface.

3. Heat emissions from one type of equipment and appliances may affect the output demand for other types. Heat loss from laundry equipment, for instance, contributes to "wild heat" which decreases the space heating equipment output requirement and adds to the space cooling requirement. The most significant of these cross-effects may need to be considered in calculating changes in net energy input resulting from changes in output and efficiency of specific end uses.

Alternative methods of projection

1. Efficiency: maintenance of existing rates

Holding efficiency rates constant would be consistent either with an assumption of no change in technology, the existing configuration of equipment within i-l-n categories being held constant, or with an assumption of a change in the relative proportions of different types of equipment so as to keep efficiency unchanged. Such a projection would show the component of growth in fuel consumption due solely to the growth in demand.

2. Efficiency: specific configurations

Changes in efficiency due to specific technological changes can be incorporated, given estimates of specific efficiencies and the rate of introduction of equipment in new housing and replacements or modifications in existing housing.

Calculation of base period and projected values

Efficiency

Specific efficiencies are shown below. There was not sufficient information available to allow for differentiation among housing types, except for water heating. Because of the difficulty of defining efficiencies for some types of equipment and appliances, as discussed in Section Two, their efficiencies were assumed equal to 1.0.

Space Heating	-	Electric	1.00	
Space Heating	-	Oil	0.60	
Space Heating	-	Gas	0.60	
Space Heating	-	Other fuels	0.60	
Water Heating	-	Electric	0.75	(Apartments - .95)
Water Heating	-	Oil	0.45	(Apartments - .75)
Water Heating	-	Gas	0.45	(Apartments - .75)
Water Heating	-	Other fuels	0.45	
Air Conditioning	-	Electric	2.34	(Coefficient of Performance)
Appliances	-	(See Table 32, Section Two)		

Input requirements

By applying these efficiencies to output requirements calculated in the preceding steps and aggregating over housing types, we arrive at the following set of input requirements.

Total Input BTUs for All Dwelling Units in Ontario
(INPUT BTU/YR - Billions)

	1971	1976
Space Heating		
Electricity	5,943	11,511
Oil	218,826	218,904
Gas	136,388	164,335
Other	11,866	11,393
	373,023	406,143
Water Heating		
Electricity	16,310	18,944
Oil	0	0
Gas	35,213	41,255
Other	821	821
	52,344	61,020
Central Airconditioning		
Electricity	281	316
Appliances		
Group 1 - Electricity	21,072	24,570
Group 2 - Electricity	5,598	6,527
Group 3 - Gas	1,811	2,052
Group 3 - Electricity	8,502	10,000
Group 3 - Other fuels	500	538
Group 4 - Gas	372	434
Group 4 - Electricity	2,824	3,292
	40,679	47,413
Total	466,327	514,892

Cautionary Note

The illustrative calculations should not be used as representative of the actual circumstances in the province of Ontario. The terms of reference for this study did not include sufficient resources for determining the actual data in all dimensions, but rather emphasized the development of a model or a structure for such calculations. It will also be difficult to reconcile these estimates with the Statistics Canada information on energy use by sector because of differences in definition of the "residential sector". A substantial part of energy usage by multiples is thought to be contained in the "commercial sector" as reported by Statistics Canada. Furthermore, our starting point is "Output BTU's" and assumed "efficiencies". The Statistics Canada measures are based on fuel consumption or input BTU's.

Sources for Aggregation

Introduction

This appendix describes the sources available for constructing a basis for aggregating energy requirements. The discussion is organized according to specific variables included in the analytical structure. Aggregation involves applying specific rates, i.e., energy requirements per dwelling unit (fixed equipment) and per household (appliances), to their corresponding numbers of dwellings or households by type and size, respectively. Calculation of energy input requirements by fuel type involve, in addition, the calculation of fuel shares, either in terms of share of output, with adjustment for relative efficiencies, or of penetration, i.e., share of dwelling units by type.

Construction of variables included in the specification but not included in this appendix involve technical engineering development. They are discussed in Section Two.

Several principal sources of data are cited in the discussion. Rather than repeat their relevant characteristics in the sections on individual variables, these are summarized here.

Census of 1971:

The Census covers all areas of the Province, with detail on the variables of interest to us reported by type of area (urban by size, rural farm and non-farm) census division and locality. One problem with this source is the lack of cross tabulation of many of the characteristics of interest.

Household Income, Facilities and Equipment Micro Data File (HIFE):

This is a file, on magnetic tape, of records from the Statistics Canada Household Expenditure and Household Facilities

surveys of 1972 (1971 data) and 1974 (1973 data). There are a large number of items pertaining to the household, the housing unit and household equipment. Because these are files on individual households, any amount of disaggregation and cross-classification is possible within the constraints of sample size which amounts to 7000-8000 for Ontario alone. There is no sub-provincial geographic identification; but type of locality is indicated, e.g., large city.

<u>Ontario Hydro Electrical Applications Survey (EAS):</u>

There have been eight surveys, conducted biennially. The most recent was in 1974. In the published reports, there is a considerable amount of regional disaggregation and cross-tabulation of appliance and equipment types, including non-electric equipment.

<u>Ontario "Assessors" Records</u>

The assessment cards completed by field surveyors contain very detailed information on the residential structure and associated fixed equipment. This is probably the best single source on the physical characteristics of the stock. The major re-assessment now in progress will make the information both current and very reliable. In future, it would be continuously updated. The major problem with this source of data is that many of the characteristics of interest are not in machine-readable form. A sample of such records, if it could be arranged, would provide joint distributions of structure and equipment characteristics by region.

1. HS_{ijl} (1,2,3,5,6,7)*

housing units by structure type (i), age (j) and regional location (l)

Type - The 1971 Census classifies structure types as:

single house attached

semi-detached or double house

row house

duplex

apartment

mobile

These types have been re-organized for the present study to form relatively homogenous groups with respect to heat loss as follows:

1. single detached (bungalow, split-level, two-storey, mobile)
2. single attached (semi-detached, duplex)
3. row
4. apartment

Age of structure - the finest breakdown for "period of construction" given in the 1971 Census is: 1971; 1970; 1969; 1966-68; 1961-65; 1951-60; 1946-50; 1921-45; 1920 or before. It is convenient to employ age groupings which are of the same time span as the fore-cast intervals. If the latter are to be a length of five years, a useful breakdown by age would be:

* Numbers in parentheses indicate step(s) in which variable appears.

1. 0 - 4 years
2. 5 - 9 years
3. 10 - 14 years
4. 15 - 19 years
5. 20 - 24 years
6. 25 years and older

Using 1971 as the base year (pending availability of 1976 Census results) this breakdown requires interpolation of units constructed 1951-60.

Region - The basis of the regional breakdown is the definition of Planning Regions employed by TEIGA. The Northeastern and Northwestern regions are merged because of their relatively small contribution to energy demand.

The regions, as defined by their component counties are as follows. (Those counties contained in whole or in part in Census Metropolitan Areas are defined as urban and have been underlined.)

1. Eastern

Dundas
Frontenac
Glengarry
Grenville
Hastings
Lanark
Leeds
Lennox & Addington
Ottawa-Carleton*
Prescott
Prince Edward
Renfrew
Russell
Stormont

* County, according to 1971 definition

2. Central

Brant
Dufferin
Durham
Haldimand
Haliburton
Halton
Muskoka
Niagara
Norfolk
Northumberland
Ontario
Peel
Peterborough
Simcoe
Toronto
Victoria
Waterloo
Wellington
Wentworth
York

3. Southwestern

Bruce
Elgin
Essex
Grey
Huron
Kent
Lambton
Middlesex
Oxford
Perth

4. Northern

Algoma
Cochrane
Manitoulin
Nippissing
Parry Sound
Sudbury
Timiskaming
Kenora
Rainy River
Thunder Bay

For 1971, HS_{ijl} can be constructed (in Step 1) from the following sources, contained in the Census, vol. II, part 3: "Housing Characteristics by Small Area":

- occupied dwellings by structure type (i) (93-727)
- occupied dwellings by period of construction (j) (93-731)

Since these are marginal distributions, the joint distribution of structure type and age must be estimated indirectly. In this study, the proportions reported for the province and its urban and rural components (93-738) are employed. The urban and rural distributions are applied to the counties designated as urban and other, respectively. Use of assessment records would obviate this indirect calculation.

2. DR_{ijl} (1,2)

disappearance rate by structure type (i), age (j) and region (l)

The available data do not appear to warrant construction of separate rates for each ijl cell. It was attempted to employ provincial tables showing structure type by period of construction for urban and rural portions in the 1961 and 1971 Censuses, to derive disappearance rates which could be applied to the individual regions and adjusted to conform with the totals by region in terms of structure type in the 1966 and 1971 Censuses. The definitions of structure type in the 1961 and the 1966 Censuses are comparable with those in 1971.

The calculations based upon this approach yielded such implausible results, however, that it had to be abandoned. Specifically, some classes of structure by age actually increased in substantial proportions, a result which could be explained either by enormous amounts of conversion or by errors in the basis of the Census figures.

The actual disappearance rates employed in the study are therefore judgemental.

3. PNH_{ijln} (4)

penetration for space heating in structure type (i), age (j) and region (l) of fuel type (n), (proportion of dwellings)

The types of fuel are:

1. oil
2. gas (including LPG)
3. electricity
4. other fuels

The "other" category would be retained to allow the inclusion of miscellaneous fuels, e.g., wood, in the base period. For projection, it could be used to introduce new types of fuel, e.g., coal-oil mixtures.

There are four principal sources of data for penetration in the existing stock.

Data on the distribution of space heating equipment by type are included in the Census of 1971 (Report No. 93-733). The classification is: steam or hot water furnace; hot air furnace; installed electric heating, stove or space heater; and other. There does not exist any cross-classification of heating equipment and fuel type.

The HIFE file contains a similar classification: steam or hot water furnace; forced hot air furnace; other hot air furnace; heating stove; electricity; cookstove or range; and other. In addition there is an item for the length of time since installation of the principal heating equipment: 5 years or less; 6 to 10 years; and more than ten

years. The latter variable, analyzed in conjunction with the age of the structure variable, would provide a good basis for estimating rates of replacement of equipment as well as contributing to estimates of efficiency.

The Assessor's records include a classification somewhat more appropriate for calculating efficiency: hot water; steam; radiant; forced; gravity; electrical; and pipeless. This information is not required to be filled in by the assessor.

The Ontario Hydro EAS includes distributions of homes by type of heating fuel, i.e., electricity, gas (including LPG), oil, coal and other. The distribution is further analyzed by municipal and rural non-farm customers.

4. PNW_{ijln} (5)

penetration of water heating equipment by structure type (i), age (j), region (l) and fuel type (n) (proportion of dwellings)

The 1971 Census includes an item "fuel used for water heating". The classification of fuels is the same as for space heating (see 3. PNH).

The HIFE file includes an item "fuel for piped hot water supply". The classification of fuels is the same as for space heating.

The EAS reports include water heating fuel by municipal and by rural non-farm customers. In each case, the dwellings in each class of fuel type are analyzed according to type of space heating fuel and presence of clothes-washing (but not dish-washing) equipment. Only electricity, gas and oil are shown. Other types of fuels are included in an "other or non" category. A "don't know" category appears not to have been distributed to the other categories. Of municipal customers renting their dwellings, 67.5% were served by gas or electric water heating; but the small proportion of oil heaters for the total sample could not account for more than a fraction of the remainder.

5. PHA_{ijln} (6)

share of dwellings with central air-cooling equipment by structure type (i), age (j), region (l), and fuel type (n)

The EAS reports show penetration of central air-conditioning by region and type of customer (rural farm; rural non-farm; local system; and municipal) but not by structure or fuel type. Distributions by structure type (single family; all others) could, however, be constructed from the data files.

The Assessor's records indicate the presence of central air-conditiong. It is not known whether fuel type is usually written in by the field assessors.

Because of the current low proportions of central units, which are in an early stage of market penetration, the base period distribution is perhaps less indicative of future trends than for space or water heating equipment. Characteristics of the units, such as capital and fuel costs in conjunction with industry and other estimates of ultimate penetration may be more relevant.

6. PNA_{inp} (7)

penetration of appliances (units per dwelling) by structure type (i) and fuel type (n) and appliance (p)

Information on major appliances is contained in the Census of 1971, the categories being: refrigerator; home freezer; electric dish-washer; automatic clothes dryer; television, black and white only; television colour only; and television, both. There is no structure-type analysis.

The HIFE file contains information on numbers of units of each appliance type, and age and fuel type (for some major appliances) for: bathtub or shower; principal cooking equipment; refrigeration equipment; freezer; washing machine (including type, as combination automatic washer-dryer, etc.); clothes dryer; radios; record players; T.V. sets; window-type air conditioners; automatic dishwashers; portable humidifiers; electric floor polishers; snow blowers; and lawn mowers.

The EAS contains information on: ranges; plug-in kettles; freezers; refrigerators; dishwashers; clothes washers; clothes dryers; window air conditioning; dehumidifiers; space heaters; television; and record/tape players. Ownership of most of these appliances is analyzed by type of locality, structure type and fuel for cooking and water and space heating.

The major sources used in the illustrative calculation were the EAS and Stat. Can. 93-738.

It is very desirable to be able to analyze the penetration of individual appliances by fuel used for central

and water heating and by the presence and fuel type of central air cooling equipment as well as by structure type. Both HIFE and EAS would be advantageous, from this viewpoint, over the Census. This type of analysis has not been performed in the illustrative calculation.

Variation in output per dwelling is largely accounted for by variation in the penetration of major appliances. An alternative forecasting method would involve establishing a sequence of appliance purchases, both major and minor. We might then assume that the probability of a household's owning a specific minor appliance is close to 1.0 (because not all households purchase in exactly the same sequence) if it owns a major appliance later in the sequence.

The proportion of such major appliances in a structure-type class could therefore be used to estimate the proportion of its "predecessor" group of minor appliances. The last major appliance in the sequence would be used also to estimate "successor" minor appliance penetration. This method would involve estimating the sequence of acquisition in the absence of detailed information on penetration. It might be an appropriate method for use with individual household records such as the HIFE file.

PART TWO:

THE COMMERCIAL SECTOR

Specification of the Structure

Introduction

The following specification of the Commercial Sector is very similar to that devised and presented in the First Part for the Residential Sector. Analogous to households and their distribution among dwellings by housing type, in the Commercial Sector we employ the idea of activity levels (which may be measured in terms of employment, sales, etc.) and their distribution among structure types, measured in areal dimensions.

Because of the much sparser information available for the Commercial Sector, compared with the Residential Sector, it has been necessary to make some simplifications in its specification. The major simplification is that energy requirements are established in input terms only, since no satisfactory efficiency levels could be derived. In spite of such simplifications, it has not been possible to establish a set of estimates of commercial energy demand by end-use for Ontario. While a number of fragmentary pieces of information have been obtained, fitting these and additional information together into a coherent whole appears to be a task beyond the resources of this project.

The specification of the projective framework is presented in the main text. In a series of appendices there are discussed: the construction of variables pertaining to the aggregation of square-foot-specific energy measures; engineering factors; modelling of individual buildings; and some considerations pertaining to cooling systems.

<u>Step 1</u>: The amount of commercial space is survived from period to period by subtracting disappearances.

(1) $CS_{j+1,kl} = CS_{jkl,t-1} * (1-DC_{jk})$

where

$CS_{j+1,kl}$ = amount of commercial space of age j+1, in structure type k and region l

$CS_{jkl,t-1}$ = amount of commercial space in previous period

DC_{jk} = disappearance rate of commercial space.

<u>Comments</u>

1. This equation allows us to calculate the distribution of commercial space by type of structure and region. This distribution will determine, jointly with other variables, the number of units and characteristics of fuel-using devices and hence the technical capacity of commercial establishments to satisfy their demand for energy in each period.

2. The age-structure of the commercial stock should be finely disaggregated for this step in order to reflect accurately the large variation in specific rates of disappearance. Subsequently, less disaggregation by age may be carried. For the purpose of reflecting changes in construction characteristics resulting from changes in building technology or codes which influence heat-loss characteristics, for instance, a simple weighted average of the characteristics of new and surviving commercial space might be employed.

3. Changes in amount of space in each category of the standing stock may result from conversions of structures to/from other uses, as well as by demolition. The disappearance rate is therefore a net figure and need not be positive, although it usually is, and will be so assumed for the present exposition. Little is known about the causes of variation in the disappearance rate or its components over time. Consequently, it is most likely that projections would employ historic rates or trends in such rates.

4. Since there is an open-ended age category, equations (1) must be modified for that category as follows:

$$\text{(1a)}\quad CS_{jo,kl} = CS_{jo-1,kl,t-1} * (1-DC_{jo-1,k}) + CS_{jo,kl,t-1} * (1-DC_{jo,k})$$

where jo represents the open-ended category.

Alternative methods of projection

1. Extrapolation

The average rate of disappearance derived for the base period is maintained over the forecast period.

2. Disappearance rate a function of growth in the economy

The rate of disappearance is made a function of structure type, age and growth in indicators of economic activity at the appropriate regional level of aggregation. The hypothesis is that economic growth affects the rate at which existing units are removed from the stock for replacement by new commercial or other uses. Forecasts of variables such as population, income and purchases of locally-produced goods and services by other regions are then employed to project disappearance rates. In addition, special factors other than energy costs affecting obsolescence, as in the replacement of small stores in mixed-use structures by shopping-centre developments, may also be introduced.

3. Disappearance rate a function of energy cost

The same procedure would be employed as in 2, but the cost of fuel by class of structure-age-region would be included as a determinant of the disappearance rate. The hypothesis is that the probability of scrappage or conversion of housing structures depends upon capitalized future rents minus costs, including fuel costs.

Step 2: The amount of space in new commercial construction by structure type and region is determined by the change in economic activity in each class plus requirements for replacement of space lost through disappearance.

$$(2) \quad CS_{j=1,kl} = \sum_i [DRDP_{il} * DPSN_{ik} + \sum_j [CS_{jkl,t-1} * DC_{jk}] * DPSN_{ik} / DPSO_{ik}]$$

where

$CS_{j=1,kl}$ = amount of commercial space created during the period by structure type (k) and region (l).

$DRDP_{il}$ = change in real economic activity during the period in sector i

$DPSN_{ik}$ = conversion factor between production and space by structure type in new commercial construction

$DPSO_{ik}$ = the same, for space existing at the start of the period

Comments:

1. It is assumed that space which disappears in each period is equal in its efficiency expressed, e.g., as dollars of sales per square foot, (the inverse of DPSO) to the overall efficiency for all structures in the standing commercial stock. If efficiency rises over time, the actual efficiency of the disappearing stock will tend to be overstated if it is assigned the average efficiency of the standing stock. The amount of the overstatement depends upon the distribution within the stock of age, efficiency and rate of disappearance. The converse holds true if efficiency decreases.

2. The equation does not make a distinction between occupied and vacant commercial space. The amount of vacant space and, in subsequent steps, differences in energy utilization between occupied and vacant space should be added to or subtracted from estimates of aggregate space, according to whether the base data are net or gross.

3. This equation and the preceding one represent one of the major channels whereby alternative assumptions about the rate and pattern of provincial growth may be introduced into the structure. The variable DRDP, in particular is the key driving force in the growth of demand for commercial space. Various assumptions about demographic change, urbanization, separation of office and manufacturing/distribution facilities, etc., may be used to calculate variations in the determinants of new construction, i.e., net demand for space and distribution and rates of demolition. The equation also makes it possible to introduce assumptions about the effects of energy costs on those determinants. It might be assumed, e.g., that increased costs of energy would accelerate introduction of space-saving arrangements, including shifts in the distribution of particular activities among types of structure.

Alternative methods of projection

1. Trend extrapolation

The simplest method of forecasting growth in commercial activity would be by some type of extrapolation of base-period trends, either on an aggregate or per capita basis.

2. Formal models

Little exists in the way of formal, quantified models of relevance for forecasting commercial activities, even at the provincial level. Part of the problem with constructing such models results from the absence of any type of regional breakdown of real production. Some investigation might be made of utilizing the provincial econometric model developed by TEIGA, or the regionalized version of CANDIDE, developed by the federal Department of Regional Economic Expansion (see their "Overview of CANDIDE-R", July, 1975). Use of either of these models, especially the latter, would make possible some type of reconciliation, albeit with intervening assumptions, of scenarios for economic growth and energy consumption as between Canada and Ontario. Either would require some allocation of growth forecasts among regions within the province.

Step 3: Heating Energy Requirements.

The energy requirements for commercial space heating is computed as the product of the amount of commercial space of a given type and region by the corresponding heating energy requirement per unit of total space.

(3) $CH_{kl} = CS_{kl} * CE_{kl}$

where

CH_{kl} = energy requirement for commercial space heating by commercial structure type (k) and region (l)

CE_{kl} = corresponding amount of energy demand per square foot of total space per year, for space heating.

Comments:

1. For large buildings (over 50,000 square feet) this term represents the heating of the peripheral area of the building only. For smaller buildings, there is no inner core so that this term represents heating of the total area.

2. The unit energy demand, CE, is a function of degree-days from October to May and of the structural characteristics of the commercial building. The functional relationship relating heating energy demand to these physical characteristics is presented in Section 3.2.8. of Appendix 2.

3. The variations in demand, CE, by structure type, k, are established through empirical investigation of the energy demand of each building type. This has been undertaken for universities and office buildings.

4. Variations in demand by age, j, are manifested in terms of structural differences in wall design. This has been taken into account in the technical function through the use of a factor. A survey of variations in commercial wall design with time will have to be undertaken to establish this factor as a function of time.

5. For this step and subsequent steps, the age subscript has been dropped. It is assumed that the energy requirement and fuel penetration coefficients chosen will reflect the age distribution of the commercial stock (e.g., the weighted average of new and surviving commercial stock in a specified period).

6. Variations in heating energy demand by region, l, are caused by a variation in degree-days, which is accounted for in the technical equation.

7. The empirical investigation described in Section 3.2.8 develops energy use per square foot factors which subsume the historical fuel mix for that class of structure. To obtain a breakout of energy use by fuel type, the resulting energy requirement must be apportioned by the implicit fuel shares. Alternatively, different unit energy demands must be developed by fuel type and then the total energy requirement can be obtained by applying penetration rates to the stock of commercial space.

Alternative methods of projection

1. New construction: extrapolation

It is assumed that changes in heat requirmenets per square foot result entirely from change in the composition of the new construction in terms of structure type and regional location. The heat requirement rates computed for each structure type in the most recent available period are maintained over the forecast period.

2. New construction: extrapolation of trend

Rates of change in the wall-design factor over the recent past by structure type and (if available) by region are maintained over the forecast period. The hypothesis is that the determinants of changes within structure types will not alter in the future.

3. New construction: specific configurations

Heat requirements in the forecast period are computed on the basis of specific architectural features. These might reflect requirements included in existing or proposed building codes. Assumptions about the future penetration of structural measures which might be expected to be adopted voluntarily, such as improved glazing, may also be introduced in this way.

4. Existing space: extrapolation

The technique is the same as would be used in 1 for new structures. It is assumed that the structural characteristics affecting heat requirements are not altered in existing space under any circumstances.

5. Existing space: specific configurations

By comparing current and proposed codes with the characteristics of existing structures, estimates could be made of the effect upon heat requirement rates of improving substandard units to the prescribed level or a judgementally-derived feasible level. As in Alternative 3, assumptions about penetration by specific fuel-saving measures could also be introduced in this way.

Step 4: Space Conditioning Energy Requirements for Large Buildings.

The energy required for commercial space conditioning is calculated by multiplying the yearly energy requirements per square foot of each of the component end-uses by their respective penetrations by fuel type and the total amount of commercial space:

$$(4) \quad CLOH_{kln} = CS_{kl} * (CHC_{kl} * PCNC_{kln} + CHH_{kl} * PCNH_{kln} + CE_{kl} * PCNCE_{kln} + CHFP_{kl} * PCNF_{kln})$$

where

$CLOH_{kln}$ = energy requirement for space conditioning equipment per year by commercial structure type (k) region (l) and fuel type (n)

CHC_{kl} = yearly cooling energy requirements per square foot by building type and region (see Section 3.2.1. of Appendix 2)

$PCNC_{kln}$ = penetration of cooling energy by fuel type

CHH_{kl} = yearly energy requirements per square foot for "reheat" in buildings with non-responsive cooling systems by building type and region (see Section 3.2.7. of Appendix 2)

$PCNH_{kln}$ = penetration of "reheat" energy for space conditioning by fuel type

CE_{kl} = peripheral heating energy requirements per square foot (see Step 3)

$PCNCE_{kln}$ = penetration of peripheral heating energy by fuel type

$CHFP_{kl}$ = yearly energy requirement per square foot for fan and pump operation, by building type and region. (See Appendix 2, Section 3.2.3.)

$PCNF_{kln}$ = penetration of fan and pump energy by fuel type.

Comments:

1. This equation allows us to introduce assumptions about the relative contribution of various types of fuel to space conditioning, and of substitution among fuels in response to price or supply constraints.

2. The space conditioning energy requirements in the form of cooling, reheating, and fan and pumping energy are functions of the various heat sources in commercial buildings, notably the lighting and the summer sunshine, and also the cooling system type, whether responsive or non-responsive (see Appendix 4.) The formulations of energy requirements per unit of commercial space as functions of the above mentioned factors are found in Appendix 2. These formulations also take into account variations in utilization as they are developed using empirical data (the utilization factors are "built-into" the formulations).

3. There are two important classifications of space-conditioning systems. Year-round systems, which are found in most large commercial buildings constructed since 1960, provide both heating and cooling, and sometimes these are performed simultaneously. For instance, the core of a building may be cooled while the periphery is heated. The more traditional arrangement involves separate heating and cooling systems, or

no cooling system whatsoever. Responsive systems vary in load with ambient temperature differences, while unresponsive systems use much the same amount of energy regardless of weather conditions. Most large buildings built between 1955 and 1975 have unresponsive systems. Since 1970, responsive year-round systems have been introduced. Their installation is increasing rapidly as a share of new construction of large buildings.

4. There is clearly a strong association between type of space-conditioning system and type of structure. Large, sealed office buildings correspond entirely with year-round systems and, in the base period, predominantly with unresponsive systems. Assumptions made in this step about the distribution of types of systems must bear some correspondence to assumptions about structure types and characteristics in Step 3.

5. For buildings with responsive cooling systems "reheat" energy requirement is zero.

6. Penetration of energy requirements by fuel type must be consistent with assumptions on penetration in buildings and by systems. For cooling, the chiller type must also be considered.

Alternative methods of projection

1. Maintenance of existing rates

Holding penetration and specific energy requirements rates constant at levels prevailing in new construction at the end of the base period would allow the "pure growth" component of demand to be examined. This scenario would be consistent with an assumption of unchanging technology regardless of price changes.

2. Extrapolation of penetration rates

The extrapolation of fuel shares from historical trends would also be consistent with an absence of response to price, and with an assumption that past determinants of market share will continue to change at the same rates.

3. Extrapolation of penetration rates with saturation reflecting assumed prices

On the basis of assumptions about future stable levels of fuel price and of technological and supply changes, long-run market shares may be derived judgementally or by reference to econometric studies. The approach to these long-run levels could be formulated as some type of growth curve.

Step 5: The energy requirements of other forms of fixed equipment by fuel type are calculated as the product of requirements per unit of floor area, amount of floor area and penetration by fuel type.

(5) $$CLOO_{kln} = CS_{kl}[L_{kln}*PCNL_{kln} + E_{kln}*PCNE_{kln} + W_{kln}*PCNW_{kln}]$$

where

$CLOO_{kln}$ = the energy requirement of fixed equipment per unit of floor area by commercial structure type (k), region (l) and fuel type (n).

L_{kln} = energy requirement for lighting equipment per unit of floor area

$PCNL_{kln}$ = penetration of lighting by fuel type as a proportion of total floor area

E_{kln} = energy requirements for the operation of elevators per unit of floor area

$PCNE_{kln}$ = penetration by fuel type of elevators as a proportion of total floor area

W_{kln} = energy requirements for water heating per unit of floor area

$PCNW_{kln}$ = penetration of water heating equipment by fuel type as a proportion of total floor area.

Comments:

1. The terms L and E embody differences in installed capacity associated with building configurations, and in rates of utilization. Buildings with large floors will tend to have more lighting capacity per unit area. Tall buildings will have more motive power for elevator operation. Assumptions about the distribution of these characteristics will need to be consistent with the assumptions of Steps 3 and 4 regarding heating and cooling requirements. See Section 3.2.2 of Appendix 2 for a discussion of the functional relationship between installed capacity utilization and energy requirement.

2. The energy required for lighting of internal spaces of commercial buildings is dependent on the installed lighting capacity (usually measured in watts /sq. ft. of commercial floor area) and the utilization per year.

3. While virtually all lighting and elevators are run by electricity, the fuel-type subscript is attached to the variables L, E, PCNL and PCNE to allow for possible self-generation in future.

4. The water heating energy requirements per unit of floor area may be assumed to be constant for each building type.

Alternative methods of projection

1. Maintenance of existing rates

Requirements per unit of floor area and penetration rates would be held constant on the assumption that neither the technical characteristics, investment in equipment nor intensity of use would be altered by future price changes, technical improvements or changes in taste.

2. Extrapolation of rates

The simplest method for projecting growth of this end use would be to extend past rates of change per unit of floor area insofar as historical information is available to allow measurement over time.

3. Requirement per unit of area: specific technical changes

Specific changes in the characteristics of lighting such as conversion to fluorescent from incandescent, reduction in lighting intensity, etc., can be introduced in terms of their unit requirements and rate of introduction in new construction and by replacement or modification of systems in existing structures. Changes in requirements of elevators would probably be effected mainly in the amounts required for new buildings of various configurations and the mix of elevators and escalators in such new structures.

Step 6: Use-Dependent Equipment Energy Demands

The energy requirements of use-dependent equipment by fuel type is computed as the product of the requirement per unit of commercial activity, the amount of such activity and penetration.

(6) $CLOU_{in} = RDP_i * OU_i * PCNU_{in}$

where

$CLOU_{in}$ = the yearly energy requirement of use-dependent equipment by sector (i) and fuel type (n)

RDP_i = real economic activity

OU_i = average requirement per unit of economic activity

$PCNU_{in}$ = penetration by fuel type

Comments:

1. Use dependent equipment refers to equipment whose presence depends upon the nature of the commercial activity, rather than upon building characteristics. Such equipment includes typewriters, cooking equipment, computers, etc. It may be installed but would normally be expected to be removed if the use changes, e.g., refrigerator rooms in a food market converted to a retail dry goods outlet.

2. Street lighting, which would be handled by this equation, is the major commercial end-use not associated with a specific type of building. The "unit of economic activity" will probably be represented by miles of street; but a measure related to governmental expenditures might be used instead.

3. Individual types of equipment under this heading require for the most part small amounts of energy compared with space conditioning or lighting. In addition they represent great diversity of specific end-uses. They will be treated, therefore, as a composite. The values of average output, penetration and utilization may, however, be calculated by aggregating up from individual equipment types.

APPENDIX 1

Sources for Aggregation

Introduction

This appendix describes the sources available for constructing a basis for aggregating energy requirements. The discussion is organized according to specific variables included in the analytical structure. Aggregation involves applying specific rates, i.e. energy requirements per square foot (fixed equipment) or per unit of economic activity (moveable equipment) to the corresponding figures for space or output. Construction of variables included in the specification but not included in this appendix involve technical-engineering development. They are discussed in Appendix 2.

1. CS_{jkl} (1, 2, 3, 4, 5)*

commercial space by age (j) type of structure (k) and region (l)

Age - Since the projections are to be performed in five-year periods, it is convenient to employ age groupings of that time span. The following breakdown is to be used:

1. 0-5 years
2. 6-10 years
3. 11-15 years
4. 16-20 years
5. 21-25 years
6. older than 25 years.

Type of structure

See Appendix 2, Section 2.0.

Region - The basis of the regional breakdown is the definition of Planning Regions employed by TEIGA. Urban counties in each region, i.e., those containing or included in metropolitan areas, are underlined. In addition, the Northeastern and Northwestern regions are merged because of their relatively small contribution to energy demand.

The regions, as defined by their component counties, are as follows. (Those counties contained in whole or in part in Census Metropolitan Areas are defined as urban and are underlined.)

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*Numbers in parentheses indicate step(s) in which variable appears.

A.1.2

1. Eastern

Dundas
Frontenac
Glengarry
Grenville
Hastings
Lanark
Leeds
Lennox & Addington
Ottawa-Carleton*
Prescott
Prince Edward
Renfrew
Russell
Stormont

2. Central

Brant
Dufferin
Durham
Haldimand
Haliburton
Halton
Muskoka
Niagara
Norfolk
Northumberland
Ontario
Peel
Peterborough
Simcoe
Toronto
Victoria
Waterloo
Wellington
Wentworth
York

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*County, according to 1971 definition

3. Southwestern

    Bruce
    Elgin
    Essex
    Grey
    Huron
    Kent
    Lambton
    Middlesex
    Oxford
    Perth

4. Northern

    Algoma
    Cochrane
    Manitoulin
    Nippissing
    Parry Sound
    Sudbury
    Timiskaming
    Kenora
    Rainy River
    Thunder Bay

There does not exist any published inventory of commercial space for the province. An inventory in the form of assessor's records does exist, however, and it contains information on age, type and location of the structure. Furthermore, the comprehensive re-assessment now in progress will make the information both current and very reliable. In future, it would be continuously updated. The major problem with this source of data is that it is not in machine-readable form. A sample of such records, if it could be arranged, would provide joint distributions of structure type and age characteristics by region.

Pending the availability of data from assessor's records, a more indirect procedure could be employed. Historical data are available from Statistics Canada on the annual value of construction by type of structure for the province as a whole (Publ. 64-201) and the value of the stock of structures in the component sectors from 1955 (as far back as 1948 for some sectors) (13-211). The amount of space in each type of structure could be estimated by dividing value of construction by the corresponding unit price, e.g., dollars per square foot, to obtain an estimate of space in terms of square feet. The distribution within the initial (1955) stock would have to be estimated separately. The relation of construction of various types of structure to growth in population, income, etc., might be used in deriving this estimate. Statistics on construction costs per square foot have been developed for the Toronto Real Estate Board, but only for their area and for the period since 1971. The Southam CANAdata service provides cost indices for Canada back to 1919, for all structures combined. Alternative sources of construction cost information include the Boeckh and Dodge services and Engineering News-Record.

Regional breakdowns of construction volume by type are available back to 1968 from the Southam Service. Estimates of construction prior to that time could, as in the case of the initial stock for the province, be derived by relating construction volumes to demographic and economic variables.

2. DC_{jk}

disappearance rate of commercial space by age (j) and structure type (k)

No centralized information is maintained on demolition or conversion of commercial space. Where permits are required for demolitions, such records are maintained by individual municipal building departments. The proportion of the commercial space lost which is represented by such permits can only be guessed. Thus, the set of values DC_{jk} will have to be established by judgemental estimates. These might be aided by the opinions of experienced real estate professionals.

3. $DRDP_{il}$ (2),

4. RDP_{i} (6)

change in, and level of real economic activity respectively, in section i, region l.

The economic sectors (i) whose activities take place in commercial structures are:

1. wholesale trade
2. retail trade
3. manufacturing (non-plant)
4. finance, insurance and real estate
5. community, business and personal services
6. public administration and defence

Ideally, DRDP would be represented by a measure of real production, e.g., value added adjusted for the price of the product. In the commercial sector, such measurements are difficult

or impossible to obtain. Where the output is in terms of services, these are difficult to standardize. In the case of distributive services, measurement of value added would involve such a host of detailed accounting adjustments as to make it impractical. This shortcoming is not a serious problem for long-term forecasting,so long as measures of gross output and/or labour inputs are available,and we are willing to make assumptions about the variation in the relation between these measures and space utilization over time. Similar assumptions would have had to be made (via the matrix DPSN) even if real measures of production were available. The best single measure of input for the commercial sector for this purpose is employment. Detailed figures are given, both by industry and urban area for large establishments in the private sector in Statistics Canada publications 72-002 and 72-004, and in 72-007, 72-009 and 72-205 for governments. Estimates for establishments of 20 employees or less are shown in publications 72-008 and 72-513. For some types of establishments, especially offices, employment is probably the best single indicator of space requirements in any event.

5. $DPSN_{ik}$ (2)

6. $DPSO_{ik}$ (2)

conversion factor between production and space in new commercial construction (DPSN) or space existing at the start of the period (DPSO) by sector (i) and type of structure (k)

This set of factors would represent the distribution of productive activity, measured by employment within each sector (or sub-sector identifiable from employment statistics) over the various types of structures. For most sectors, employment is located predominantly in one or two types of structures - wholesalers in warehouses and stores, retailers in stores, etc. Rough estimates are probably quite adequate in these situations. Somewhat more problematic is the identification of the location of the administrative personnel as between the "plant" and distinct office facilities. Data exist for resolving this problem, but they involve special analysis, possibly utilizing data at the individual establishment level. Primary sources for such information would include Dun and Bradstreet, and for manufacturers the Canadian Manufacturers' Association Trade Index and Scott's Directory. A less precise analysis could be performed on the basis of wage earner vs. salaried employee breakout in the Statistics Canada publications cited above.

7. $PCNH_{kln}$ (4)

8. $PCNC_{kln}$ (4)

penetration of heating/cooling equipment, respectively, by structure type (k) region (l) and fuel type (n).

The relationship between types of systems and the size, age and type of structure has already been discussed. The penetration term allows the potential space conditioning requirements relative to a specific degree-day measurement to be adjusted for the actual incidence of cooling equipment by fuel type. For buildings with heating only, the penetration of cooling equipment would be zero. For buildings with year-round systems, the penetration would be equal for each fuel type, i.e., the same system heats and cools. This formulation allows the impact, e.g., of installing window air-conditioners in existing buildings to be studied.

11. $PCNL_{kln}$ (5)

$PCNE_{kln}$ (5)

penetration of lighting and of elevator operation, respectively, by fuel type (n) as a proportion of total floor area by structure type (k) and region (l).

These terms are included to allow for self-generation. The proportions in any class for fuels other than electricity are probably negligible in the base period but are expected to grow in future.

12. $PCNW_{kln}$ (5)

penetration by fuel type of water heating equipment as a proportion of total floor area.

For most commercial structures, particularly large structures, the type of fuel is likely to be identical with the fuel chosen for space heating/cooling.

13. OU_i (6)

average energy requirement of use-dependent equipment by sector (i) per unit of economic activity.

Since it is proposed to measure economic activity (RDP_i) in terms of employment, this variable would be an output capacity, e.g., in BTU's, per employee.

This variable would correspond with a rated capacity adjusted for average utilization. The various types of equipment

would be aggregated to achieve a total figure for all use-dependent equipment. This aggregation could be accomplished in one of two ways. Individual types of equipment could be enumerated, their capacities adjusted for utilization, and the results summed by each structure type, using weights corresponding to the average number of units of each appliance type in the corresponding structure type. The alternative would be to examine actual fuel consumption, adjusted for consumption by fixed equipment, for establishments with different "families" of equipment.

Each of these approaches involves measurement problems. The complete enumeration indicated for the former approach does not exist and would require a survey, which might be very difficult to implement. In the latter approach, the separation of consumption by this class of equipment versus structure-related equipment would be very difficult in practice.

A less detailed approach, combining elements of each of the above would appear to be practicable. This approach would involve observations on the actual overall loads in different types of establishments. Such surveys have been made in various locations. The portion of the load attributable to building-related equipment would be subtracted.

14. $PCNU_{in}$ (6)

penetration of use-dependent equipment by sector (i), by fuel type (n).

Some information on penetration is available from Ontario Hydro special marketing studies, e.g., "Evaluation of Electrical Energy Management Potentials in the Commercial Market". Since the bulk of capacity in this class is electric, estimation problems will relate primarily to the relatively few uses where there is significant penetration by other fuels.

Summary and Recommendations

No calculations have been made for the Commercial Sector. The data which would be required to implement the structure described in the main text of this section, even in an abridged form, could be constructed only with resources beyond those of this project. Problems with the acquisition of specific engineering measures for different building types and uses are described briefly in Appendix 2.

Problems in the construction of some of the critical variables used for aggregation which have been discussed in this appendix and possible solutions (which would have to be addressed before an initial calculation could be made) include the following.

Commercial Space (CS) -- There are two approaches open. The Provincial Assessor's records contain information which would allow construction of estimates of square footage of the commercial stock and of joint distribution of characteristics within the stock which is specified in the analytical structure.

Converting data from file card to machine-readable form need not be a major undertaking, as a sample of 3-5,000 records would appear to be adequate for the purpose. The alternative would be to examine different types of commercial structure individually. Retail space data is not available for the province (it has been obtained for Ottawa-Carleton), but space in shopping centres appears annually in Statistics Canada 63-214. An estimate of office space could be obtained

by expanding the figures available from federal and provincial sources by the ratio of total office to governmental office employment. Schools could be estimated by enrollment x 400 square feet. For other types, such as hotels, warehouses and garages data are not directly available on a provincial basis, but might be obtained from planning departments in a few representative localities. The estimates of floor space per capita compiled by the B.C. Energy Commission ("British Columbia's Energy Outlook, 1976-1991") would be a useful supplement in this connection. This approach by itself would not provide much information either directly on type of HVAC system or on the age distribution or fuel types from which the distribution of system types might otherwise be inferred. Lack of an adequate age distribution would also severely limit the approach whereby energy output and input requirement changes, from period to period, are aggregated from age-specific values in the survived stock.

Conversion factor between production and space (DPSN/DPSO) -- There does not appear to be any information available on a consistent basis. A survey of existing buildings and of real estate and construction firms might have to be made.

Penetration of heating/cooling equipment (PCNH/PCNC) -- The data available for government buildings might be generalized. For some types of buildings (see Appendix 2), heating and cooling, as well as lighting would need to be combined.

APPENDIX 2

Technical Considerations

COMMERCIAL SECTOR

INTRODUCTION

The following is a description of the technical aspects of the energy demand model for the commercial sector in Ontario. The technical study involves:

1) the classification of commercial buildings into characteristic building types with respect to their function and size;
2) the identification of the various end-uses of energy (cooling, lighting, etc.) within each building type; and
3) the quantification of energy demand for each of these end-use categories in terms of accountable physical characteristics.

The energy demand quantities to be obtained from the model will be in terms of yearly energy consumption per unit of commercial space for selected building types (i.e. kwh/sq.ft.yr). Thus, the complete accounting of energy demand for the commercial sector in a given year requires an assessment of existing commercial space for each building type. This, when multiplied by the energy demand per square foot per year would yield the total demand for that building type for the province.

The individual functions that are used to calculate the demand for the end use categories (cooling, lighting, etc.) were designed to permit the accounting of potential major changes in hardware design practices and standards that are likely to occur in the future. This will allow the assessment of savings for basic conservation measures.

1.0 Classification of Commercial Building by Type

The commercial stock of buildings in Ontario may be categorized in terms of building functions as follows:

1. Office buildings;
2. Mercantile buildings; shopping centres, stores (retail, wholesale);
3. Universities;
4. Schools;
5. Hospitals;
6. Hotels, clubs, restaurants;
7. Warehouses, storehouses, refrigerated storage, grain elevators;

and 8. Miscellaneous; garages, theatres, arenas, churches, gymnasiums, aeroplane hangers, fan buildings, laundries and small businesses.

These include all the building types that are monitored by Statistics Canada for construction activity. The categories were chosen to reflect the various uses which are characteristic of buildings. Size of institution is taken into consideration in that smaller types of commercial buildings are lumped into the miscellaneous category.

It may be noted that universities include a variety of building types: lecture halls, office buildings, student residences, and gymnasiums, which may fall into other categories, yet are included under "Universities", since the central or group heating schemes associated with this institution facilitate this energy accounting process. Furthermore the majority of buildings in universities have the same basic function of providing classroom and office facilities.

Unaccounted for in these classifications are the various commercial enterprises which fall under municipal government jurisdiction: road construction, street lighting, traffic control etc. A detailed study will be required to account for municipal government energy expenditures.

Also excluded from these categories are apartment buildings which are accounted for in the residential model.

2.0 Energy End-Use Categories

The end-uses for energy in the commercial sector may be classified according to the basic functions for which energy is required. These may be enumerated as:

1. cooling;
2. lighting;
3. fans and pumps;
4. auxiliary power;
5. elevators;
6. water heating;
7. reheating;
8. heating (peripheral);

and 9. process power.

These categories are defined below with respect to commercial energy use:

1. Cooling refers to the cooling energy requirements for space conditioning. These needs arise because of heat gains from lighting, human activity and heat transfer from the outdoors in the summer. (This category excludes refrigeration which is discussed in section 9).

2. Lighting includes all types of lighting associated with building operation and includes outdoor lighting used for advertisement purposes. (It will be noted in the next chapter that outdoor lighting has not been modelled in this study due to lack of data).

3. Fans and pumps are used to circulate the ventilating air in the heating and cooling systems.

4. Auxiliary power is associated with the "plug-in" type of equipment-typewriters, calculators, etc.

5. Elevators applies only to high rise buildings (more than three floors) and is the energy required for elevator operations.

6. Water Heating is for the domestic use of hot water in washrooms. (Water heating for radiator-heating systems falls under heating, category #8).

7. Reheating applies to a constant volume system of space conditioning. It is the heat required to bring the cool air stream from the chillers to the required ventilating temperature, when the total cooling affect from the chiller is not needed. (See Appendix 4 for an explanation).

8. Peripheral Heating applies to large buildings (commercial space over 50,000 sq.ft.) where only the space closest to the peripheral walls is heated during the colder months of the year. This excludes the heating of ventilating air (see category #7). For smaller buildings, the peripheral heating becomes the total heating, and this may be calculated using the equivalent degree day method developed for the residential sector.

9. Process power is the energy associated with the operation of special commercial activities in which the energy used represents a fraction of the value added in the product (i.e. the commercial enterprise is much like an industry). Examples of such enterprises are computing firms where the computer has a direct energy requirement and an indirect one

in the form of space cooling; food outlets (wholesale and retail) with extensive refrigerating hardware; and the entire communications "industry", including newspaper publishers, radio and television networks, telephone companies, etc.

3.0 Demand Analysis

Ideally, a detailed hour-by-hour analysis of the heat transfer phenomena of each type of commercial building would accurately account for the energy used per unit of commercial space in the province of Ontario. This would also permit accurate assessment of a host of conservation measures that are linked to building structural design, outlay, and space conditioning systems. However, these methods of analysis (see Appendix 3 for a description) were not meant for macro-modelling purposes, and this is reflected in the level of data required for calculation (details of structures and system design) and the high cost for the analysis of a single building. Furthermore, the extreme diversity of commercial building structures makes it unlikely that a typical building configuration could be established in order to run such programs.

The approach which is put forward in this study is empirical in nature. It consists of relating the various end-use demands cited in Section 2, to the dominant physical characteristics of those end-use functions. The reasoning and data base which were used to arrive at these relationships are discussed in detail in the following sections.

3.1 Data Base for the Empirical Study

The Ontario Ministries of Energy, and of Colleges and Universities have been sponsoring a program of energy conservation at Carleton University. This program has involved the detailed energy consumption monitoring of 24 university buildings as part of a procedure to gauge the effectiveness of various energy conservation measures that were implemented at the University. (The progress of this project to date has been reported by Findlay(1).) A by-product of these studies has been the organization of an extensive data base for the operation of Carleton University buildings, including operation data before and after conservation measures were implemented. Access to operating characteristics of other Ontario universities has also added to the information base for our study. In addition pertinent weather data (sunshine hours, degree days, etc.) and building design characteristics (lighting levels, space conditioning systems, basic geometry, etc.) were recorded during the span of the program.

The data base used in the study was constructed from the measurement of individually metered buildings. The disaggregation of this information into specific end-use categories was made possible through comparison of the buildings being monitored. For example, lights, fans and elevators, which use electricity measured through a single meter, are accounted for through separate equations. U.S. studies in commercial energy demand are referenced in support of this disaggregation procedure (2, 3, 4, 5).

3.2 Empirical Energy End-Use Functions

The energy end-use functions to be presented in detail were derived empirically, using the basic data described in the previous section. The functions will be presented in general form, as they are believed to be valid for all building types. Sample coefficients of the equations are presented, and these apply to university and office type buildings in Ontario, operating for 2500 hours per year, with 900 hours of cooling per year.

The application of these functions within the framework of a general accounting model for the Ontario commercial sector will require:

1. an extension of the array of coefficients such that the consumption of other building types may be accounted for;

2. classification of end-use demand by fuel type; and

3. generalization of the equations to account for the wide range of operating hours that are current practice for commercial buildings. These steps will be discussed in section 3.4.

3.2.1 Space Cooling

The space cooling is a function of building heat gains due to people and machinery, external heat, installed internal lighting intensity, and the cooling system. The cooling system may be either responsive or non-responsive (see appendix 4 for a description of the differences, and market penetration) and these show large differences in energy consumption characteristics. Furthermore the chillers may be either electrical-mechanical or absorptive. The absorption chillers use large portions of steam heat originating from fossil fired boilers as part of the cooling process, whereas the electric chillers work on the same principle as the window air conditioner. The differences in energy consumption are manifested in terms of quantity and fuel type. The absorption chillers use fossil fuels directly, in quantities about 3½ times that of the electric chillers. (In terms of natural resource usage, however, this difference is narrowed considerably due to electric conversion and transmission losses). These effects are taken into account in the functions through factors and penetrations that reflect chiller fuel type and cooling system type.

Function:

$$\text{Cooling} = C_1 + \frac{(C_2 \times \text{lighting capacity})}{2.5} \times F_1 \times F_5 \times \text{Penetration}$$

Cooling: in kwh/sq.ft.yr.

C_1 : constant to account for heat gain from people, machinery, solar gain and heat transfer through the fabric, and losses or inefficiencies of the cooling system, kwh/sq.ft.yr.

For office buildings $C_1 = 0.9$

C_2 : constant that relates the installed interior lighting capacity to the energy required to offset its heating effect.

For office buildings $C_2 = 2.1$

Lighting Capacity: Installed lighting capacity per unit of floor space in watts/sq.ft. (see next section).

System Factor(F_1): Dimensionless unit to account for the difference between a responsive system and non-responsive system.

Responsive = 1 Non-Responsive = 1.66

(subject to further investigation).

Chiller Type Factor (F_5) : Dimensionless unit to account for the difference between electric and absorption chillers.

Absorption = 3.4 Electric = 1.0

Penetration : The fraction of buildings of a select building type with cooling of interior space. This factor will also have to account for the penetrations of system types (responsive and non-responsive) and chiller types (aborption and electric), to be consistent in the accounting framework.

Sample Equation : Non-responsive office building with absorption chiller

$F_1 = 1.66$

$F_5 = 3.4$

$$\text{Cooling} = \left[0.9 + \left(2.1 \times \frac{\text{lighting capacity}}{2.5}\right) \times 1.66 \times 3.4 \times \text{penetration}\right]$$

3.2.2 Lighting Energy Requirements

The lighting energy requirements are a function of installed capacity and utilization. The installed capacity may be as high as 3.5 to 4.5 watts/sq.ft. for older office buildings. This number tends towards 2.5 watts/sq.ft. for the newer buildings. These figures apply only to indoor lighting.
(Separate studies will be required to establish energy used for lighting of external building areas and for commercial building advertisement).

Function:

$$\text{Lighting} = C_3 \times \frac{\text{Installed Capacity}}{2.5}$$

Lighting: in kwh/sq.ft.yr. of indoor lighting

C_3 : proportionality constant which accounts for utilization hours per year (presently based on 2500 hr/yr) losses, etc.

For newer office buildings

$C_3 = 8.3$

Installed capacity: in watts/sq.ft. of indoor lighting

Sample Equation : For newer office buildings

$C_3 = 8.3$

Installed capacity = 2.5 watts/sq.ft.

$$\text{Lighting} = 8.3 \left(\frac{2.5}{2.5}\right) \text{ kwh/sq.ft.yr.}$$

$$= 8.3 \text{ kwh/sq.ft.yr.}$$

3.2.3 Fans and Pumps

The electricity required for fan and pump operations is strongly dependent on the cooling load as defined by lighting intensity, and on cooling system type.

<u>Function:</u>

$$\text{Fan \& Pump} = \left(\left(\frac{\text{Lighting Capacity}}{2.5}\right)^2 \times C_4 \right) \times F_2$$

Fan & Pump : in kwh/sq.ft.yr.

Lighting Capacity : watts per square foot

C_4 : constant relating lighting capacity to fan and pump energy use in kwh /sq.ft.yr.
For office buildings,
$C_4 = 1.5$

F_2 : System type factor (dimensionless)
Responsive $F_2 = 1$
Non-responsive $F_2 = 2.25$

<u>Sample Equation:</u> For new office buildings and a non-responsive system

$C_4 = 1.5$

Lighting capacity = 2.5 watts/sq.ft.

$F_2 = 2.25$

$$\text{Fans \& Pumps} = \left(\left(\frac{2.5}{2.5}\right)^2 \times 1.5 \right) \times 2.25$$

$$= 3.38 \text{ kwh /sq.ft.yr.}$$

3.2.4 Auxiliary Power

Auxiliary power refers to the electricity required to operate auxiliary machinery: typewriters calculators, etc. This value is simply a function of building type.

Function:

Auxiliary power = C_5

C_5 : in kwh/sq.ft.yr.

$= 0.3\frac{\text{kwh}}{\text{sq.ft.yr.}}$ for office buildings

3.2.5 Elevators

The electricity required to power elevators is roughly a function of the number of floors of a building, plus some constant energy requirement for standby energy usage etc. Generally, only buildings with more than three floors have elevators.

<u>Function</u>:

Elevator = C_6 + (C_7 x number of floors)

Elevator = energy requirement in kwh/sq.ft.yr.

C_6 : constant to account for requirements not related to the number of floors

$$C_6 = 0.3 \frac{\text{kwh}}{\text{sq.ft.yr.}}$$ for office buildings

C_7 : Constant relating number of floors to the energy requirement

$$C_7 = 0.04 \left(\frac{\text{kwh}}{\text{sq.ft. floors}}\right)$$ for office buildings

<u>Sample Equation</u>: Office buildings of greater than 3 floors.

$C_6 = 0.3$

$C_7 = 0.04$

Elevator = 0.3 + (0.04 x number of floors) kwh/sq.ft.yr.

3.2.6 Water Heating

The water heating requirements for commercial buildings refer to the domestic hot water usage. This quantity is related to building type.

Function:

Water heating $= C_8$

C_8 = water heating energy requirement by building type.

For office buildings $C_8 = 1.5$ kwh /sq.ft.yr.

3.2.7 Reheating

The function of the "reheat" in a non-responsive cooling system is essentially to control the temperature of the conditioned space. This is done by heating the cool ventilating air (constant volume, constant temperature) wherever certain conditions prevail. (See Appendix 4 for an explanation). The functional relationship for reheat thus includes a measure of the installed capacity for cooling which is a function of lighting capacity, and the summer climate variations for the province.

<u>Function</u>:

$$\text{Reheat} = \left(\left(C_9 + \left(C_{10} \times \frac{\text{lighting capacity}}{2.5}\right)\right) - (\text{summer sunshine hours} \times C_{11})\right) \times F_3 \times \text{penetration}$$

Reheat: Reheating energy in kwh/sq.ft.yr.

C_9 : Constant to represent cooling loads other than lighting, and excess cooling capacity.

C_9 = 2 kwh /sq.ft.yr. for office buildings

C_{10} : factor relating the lighting capacity to cooling load.

C_{10} = 33 kwh/sq.ft.yr. for office buildings.

Lighting capacity: Installed lighting capacity in watts/sq.ft.

Summer sunshine hours : hours of sunshine during the cooling season (May to October inclusive) = about 1100.

C_{11} : relates sunshine hours to the heat gain of the building from external sources in kilowatts.

Office buildings: $C_{11} = 1.59 \times 10^{-2}$ kw.

F_3 : system type factor (dimensionless)

non-responsive $F_3 = 1$

responsive $F_3 = 0$

Penetration : the penetration of non-responsive space cooling systems in commercial buildings.

Sample Equation: New office building; non-responsive lighting capacity = 2.5 $\frac{\text{watts}}{\text{sq.ft.}}$

$$\text{Reheat} = ((2. + 13. \times 2.5) - (\text{summer sunshine hours} \times 1.59 \times 10^{-2}) \times 1 \times \text{penetration}$$

3.2.8 Peripheral Heating

The heating energy demand of commercial buildings relates to peripheral space control only, and can be handled in a similar way to residential space heating. However, the detailed calculation procedure presented in the residential chapter is too complex for the degree of accuracy sought here. Rather, the peripheral heating load is related largely to degree days from October to May and a simplified expression will be used to account for this fact. Wall construction differences will be represented by a construction factor. This function applies to buildings with greater than 50,000 square feet of floor area. Smaller buildings will have heating systems much like residences so that the residential model could be used .

<u>Function</u>:

$$\text{Heating} = C_{12} + (\text{Degree days}_{(\text{Oct-May})} \times C_{13}) \times F_4$$

Heating: in kwh/sq.ft.yr. in the fuel mix that is used for that type of building.

C_{12} : account for losses and other heat loads not accounted for by the degree days.

For office buildings greater than 50,000 sq.ft.:

C_{12} = 3. kwh/sq.ft.yr.

Degree $\text{Days}_{(\text{Oct-May})}$: the degree days based on 65°F between the months of October to May inclusive. This is calculated by the Degree $\text{Days}_{(\text{O-M})}$ = Degree $\text{Days}_{(\text{total})}$

$$\times[94-(\text{latitude}-42^{\circ})] \times .483$$

C_{13} : Heat loss factor, including system energy conversion factors, and wall characteristics. Relates degree days to fuel consumption per unit space.

For large office buildings $C_{13} = 790 \times 10^{-6}$ kwhrs/sq.ft.$^{\circ}$F day

F_4 : Factor to account for commercial wall design improvements which may occur in the future. Such changes may include higher insulation, changes in window design and area, etc.

For current office buildings $F_4 = 1$

3.2.9 Process Power

As discussed in the previous chapter, process power has been included to account for specialized commercial processes which require an energy input. The recommended approach is to investigate these various commercial processes, independently of building type.

<u>Function</u>:

Process power = C_{14}

C_{14} : in kwh/sq.ft.yr.

(further investigation is recommended).

3.3 Summary of Equations and Constants

The proposed technical functions that will account for commercial energy demand are listed as follows:

1. Cooling = $(C_1 + (C_2 \times \frac{\text{lighting capacity}}{2.5})) \times F_1 \times F_5 \times$ penetration,
2. Lighting = $C_3 \times \frac{\text{lighting capacity}}{2.5}$
3. Fans and pumps = $((\frac{\text{lighting capacity}}{2.5})^2 \times C_4) \times F_2$
4. Auxiliary power = C_5
5. Elevators = $C_6 + (C_7 \times$ number of floors)
6. Water heating = C_8
7. Reheat = $(C_9 + (C_{10} \times \frac{\text{lighting capacity}}{2.5})$ - (summer sunshine hours $\times C_{11})) \times F_3 \times$ penetration
8. Heating = $(C_{12} + (\text{Degree days}_{(\text{Oct-May})} \times C_{13})) \times F_4$
9. Process power = C_{14}

The functions are completed by the following set of constants which apply to universities and office buildings.

Constants for the Demand Functions - Universities and Office Buildings.

C_1 = 0.9 kwh/sq.ft.yr.

C_2 = 2.1 kwh/sq.ft.yr.

C_3 = 8.3 kwh/sq.ft.yr.

C_4 = 1.5 kwh/sq.ft.yr.

C_5 = 0.3 kwh/sq.ft.yr.

C_6 = 0.3 kwh/sq.ft.yr.

C_7 = 0.04 kwh/(sq.ft.yr. floor)

C_8 = 1.5 kwh/sq.ft.yr.

C_9 = 2.0 kwh/sq.ft.yr.

C_{10} = 33 kwh/sq.ft.yr.

C_{11} = 1.59×10^{-2} kw

C_{12} = 3.0 kwh/sq.ft.yr.

C_{13} = 790×10^{-6} kwh/sq.ft. ^{o}F day

C_{14} = 0 (requiring extensive investigations)

	RESPONSIVE	NON-RESPONSIVE
F_1:	1	1.66
F_2:	1	2.25
F_3:	0	1

F_4: 1 (for modern buildings)

F_5: 3.4 (absorption chillers) 1.0 (electric chillers)

3.4 A General Model for the Commercial Sector

The end-use functions described in the previous section were derived using limited operation data, but were structured in such a way as to facilitate the development of a general energy accounting model for the commercial sector. The steps which are necessary to generalize the equations in their present form are described below.

3.4.1 Variation by Building Type

The form of the end-use functions will not vary by building type, as functions relate unit energy usage to fundamental design characteristics such as installed lighting capacity per unit area. The function coefficients will vary by building type to reflect the different consumption characteristics of each type. The complete specification of the model would thus include a matrix of the fourteen coefficients and five factors for each building type. These would be derived using typical consumption data as was done for the university buildings. The completion of this matrix of coefficients has not been undertaken in the present study; however this task is considerably simplified by the fact that the energy end-use demands are system oriented rather than building oriented so that many of the coefficients will either be similar to the ones obtained for universities, or will be zero in the absence of that end-use.

3.4.2 Aggregation by Energy Type

The energy consumption specified by the equations is in kilowatt hours per square foot per year. This is a measure of the energy delivered

to the building from electric and fossil fuel utilities. However, it will be noted that fuel type is not specified in the equation, and this is undertaken here.

Electrical Energy Demand

The following end-uses usually involve the consumption of electricity^

- lighting,
- fans and pumps,
- auxiliary power,
- elevators,
- process power.

An exception to this rule is the electricity generated from on-site standby diesel generators which are usually only used during emergencies. In these cases the delivered fuel to the buildings for end use is diesel oil, but this amount is considered small. The concept of "total energy systems" for the supply of both electricity and heat to large commercial structures such as shopping centres, would cause a shift in energy demand from electricity to fuel oil for these end-uses, but these systems are not common as yet in Ontario.

Chillers used in commercial cooling systems are usually electric. The total demand for electricity due to commercial cooling would thus be calculated using function #1, with F5 equalling 1.0 and with the penetration reflecting the number of electric chillers as a fraction of total number of buildings of that type.

Similarly some commercial buildings are powered entirely from electricity; thus, heating, reheating, and water heating will also have penetrations into the electricity market.

Fossil Fuel Demands

The end-use demand energies which are commonly in the form of fossil fuels include:

cooling,

water heating,

reheating,

heating,

process power.

As all of these energies may be supplied through oil in various forms, gas and electricity penetration figures which are a function of fuel type will have to be developed for each of these functions by building type.

3.4.3 Variations in Hours of Operation

The proposed end-use functions are based on 2500 hours of commercial operation per year, with 900 hours of cooling per year. The energy consumed in the end-use categories are directly proportional to these hours of operation. Cooling and reheating energy requirements are in proportion to the actual number of cooling hours per year relative to 900, whereas the rest of the end-uses energy requirements are proportional to commercial operating hours relative to a "standard" of 2500.

4.0 Summary

The specification of a technical model for the accounting of commercial energy demand in Ontario has been undertaken. The model is presented in the form of functional relationships that relate energy end-use per unit of commercial space to accountable physical quantities related to building type and climate.

The coefficients for these functions have been developed for university and office types of buildings. Further research will be required to produce the coefficients for the six other building types in the commercial sector.

General surveys to gather the following information will have to be undertaken for a complete accounting of energy demand.

1) commercial floor area in use for a given year, for each building type;
2) penetration of fuel types for the end-use categories by building type;
3) hours of general operation per year and hours of cooling per year, by building type;
4) the penetration of cooling by system type and chiller type.

In addition, some areas of commercial energy demand have not been modelled here, as they were not oriented to building energy demand, making it difficult to account for these in a general way. These energy demands are institution oriented: municipal works, communications industry (radio, TV, newspaper) and other small businesses requiring process energy. Lighting of external commercial building faces for advertisement purposes requires further investigation.

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APPENDIX 3

Energy Modelling of Individual Commercial Buildings

APPENDIX 3

ENERGY MODELLING OF INDIVIDUAL COMMERCIAL BUILDINGS

The "degree day" method for estimating annual fuel consumption is based on a measure set of average conditions so that it can be successfully applied only to buildings which do not vary substantially in their thermal characteristics from such averages. It can be applied to residential structures with a level of accuracy which depends on the degree of deviation from the average conditions upon which the degree day method was based.

However, the diverse architectural and operational characteristics of commercial structures requires an estimating procedure which is not based on averages.

This is due to the fact that in a commercial building the internal and external factors which determine the thermal loads are constantly changing. Not only do these loads change substantially from day to day but also from hour to hour.

According to the ASHRAE Standard 90-75 the building heating and cooling load calculation procedure should be of sufficient detail to permit the evaluation of the interacting effects of:

1. Building data - orientation
   - size
   - mass
   - shape
   - air
   - moisture
   - heat transfer characteristics

(2) Hourly Climatic data - temperature
- humidity
- solar radiation
- wind

(3) Hourly internal heat generation - lighting
- machinery
- occupancy.

Further, factors such as:

(1) high peak internal loads (mainly due to occupancy);

and (2) complex heat recovery systems whose energy requirements depend on the simultaneous demand for electrical heating and cooling energy,

contribute to the need for an hour by hour evaluation each day of the commercial buildings thermal characteristics.

Because of such complex factors, estimation of a commercial building's energy consumption based on design performance criteria leads to gross inaccuracies. Therefore, a calculation procedure which can reflect the hour by hour interactive effects of:

(1) constant physical characteristics of building

(2) the changing internal conditions (occupancy and operational schedules)

and (3) the changing external environment (ambient weather conditions and solar radiation),

is most suitable for accurately predicting the energy requirements of a building's HVAC (Heating Ventilating and Air Conditioning) system.

No standard techniques have as yet been developed. However, the ASHRAE Task Group on Energy requirements for Heating and Cooling buildings have derived a set of procedures for the development of a suitable program. These are:

(1) Procedures for determining heating and cooling loads for computerized energy calculations (ASHRAE Bulletin 1971).

(2) "Proposed Procedures" for simulating the performance of components and systems for energy calculations (ASHRAE Bulletin 1971).

It should be noted that private consulting firms, such as Ross F. Meriwether and Associates, have developed advanced techniques of building systems analysis which take into account the factors listed above. The Canadian Federal Department of Public Works, through an agreement with R.F. Meriwether has made that series of programs available to Canadian users, free of royalty charges. Although the complexity of this program makes it impractical for use as a general modelling tool, it may play an important role in the evaluation of specific conservation measures in commercial buildings.

Other Techniques

Prior to the availability of such simulation techniques* a variety of techniques have been used. These are delineated as follows:

(1) Adjusted degree day method - here a revised base temperature is calculated. This is usually the balance temperature of the building under some set of conditions. However, the

*(and sometimes instead of them because of time, cost, availability, or personal preferences)

adjusted concepts do not provide for the constantly changing relationship between internal and external loads.

(2) 'Bin' method

This method is suggested by ASHRAE 90-75 as a simple alternative to the simulation approach. It is called the 'Bin' method or temperature frequency method. The principle of the technique is as follows: the heat gain or loss from a building is calculated and expressed as a function of ambient dry bulb temperature when the building is occupied and unoccupied. A count is made of the number of times each month that the average temperature for the day was within a certain range of a bin. These temperature bins are normally 5 or 10 ^{o}F increments and are further categorized by periods of the day corresponding to normal working/non working hours (e.g. 9:30 a.m. - 5:30 p.m.).

However, this method still assumes that the internal load and solar radiation loads are constant during the operating period covered by a temperature bin. This can be overcome somewhat by having operating periods on an hourly rather than an 8-hour basis. However, this does not allow for variation in occupancy and/or operational days during the month. It is though, a considerable improvement over the degree day method.

APPENDIX 4

Responsive and Non-Responsive Cooling Systems

APPENDIX 4

RESPONSIVE AND NON-RESPONSIVE COOLING SYSTEMS

Before about 1950 commercial buildings were heated in winter, but only a few were cooled in summer. Heating and cooling were hardly ever run at the same time. Such buildings require heat in proportion to the difference in temperature between inside and outside. Their annual energy requirements follow the degree-day concept. That is, the colder the winter, the more energy is used. At higher temperatures windows are opened to get a high ventilation rate and air movement.

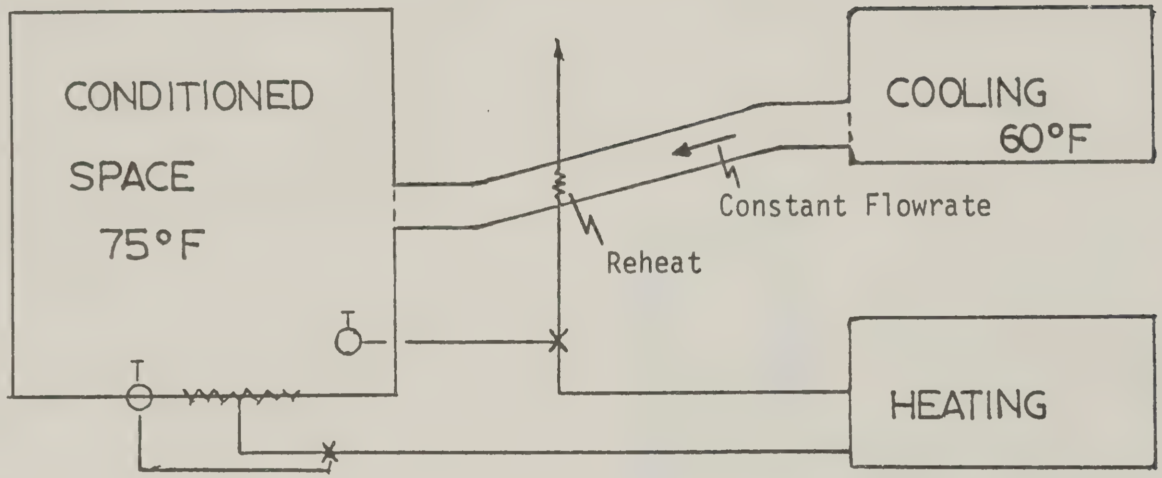
Since 1960, larger commercial buildings have been fitted with year-round air conditioning systems of the non-responsive type (1950-1960 can be considered a transition period). These systems provide heating and cooling at the same time: air flows from the chiller at constant flow rate and temperature and if the full cooling is not required by the conditioned space, the cool air is reheated either by mixing in warm air from the heating source or by a heating coil, as shown in figure 1. Thus, on cool summer days or days without sunshine, and on days of low building activity (activity creates "wild heat") much of the cooling air must be reheated to achieve the required ventilating temperature.

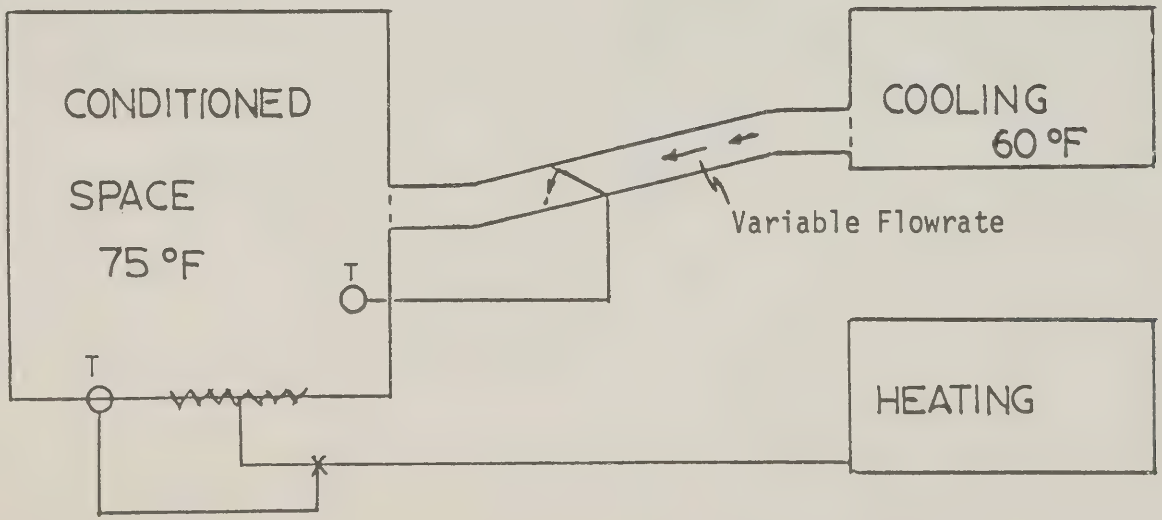
Only a few large commercial buildings since 1950 have had systems whose energy loads respond to climate. Since 1970 year round systems have been developed which respond to climate load and operate much more economically. Their installation is increasing rapidly. A certain amount of modification of existing unresponsive systems to improve their economy is also going on.

The responsive system, schematically represented in figure 1, controls the amount of cooling delivered to the space through air flow control. Thus, only the energy required to cool the space is produced by the chiller. When little cooling is needed, little cool air is sent through the conditioned space.

FIGURE 1

CONSTANT VOLUME SYSTEM





VARIABLE VOLUME SYSTEM

PART THREE:

TRENDS IN ENERGY DEMAND IN THE RESIDENTIAL AND COMMERCIAL SECTORS

During the fifteen-year period 1958-1972 inclusive, energy consumption in Canada more than doubled, while in Ontario the proportionate increase was slightly less, at 99%, bringing the Province's share to just over one-third of total Canadian energy consumption. As between the two sectors, domestic and commercial, domestic consumption increased nationally by over three-quarters, while for Ontario the increase was only one-half. In the commercial sector, on the other hand, the proportional increase was much higher than for all sectors combined, being over 350%. For Ontario, the rate of increase was slightly higher than for Canada. An analysis of these trends is shown in Table 1.

Table 1

Growth in Energy Consumption

	Canada			Ontario		
	1958	1972	% Change	1958	1972	% Change
All Sectors						
10^{12}BTU	2638.4	5504.0	108.6	981.3	1953.6	99.1
% of Canada	-	-	-	37.9	35.5	-2.4*
Domestic						
10^{12}BTU	639.2	1131.5	77.0	263.9	397.1	50.4
% of Canada	-	-	-	41.2	35.0	-6.2
% of Total	24.2	20.5	-3.7*	26.9	20.3	-6.6*
Commercial						
10^{12}BTU	186.4	828.7	344.5	68.4	309.5	352.4
% of Canada	-	-	-	36.6	37.3	0.7
% of Total	7.0	15.0	8.0*	6.9	15.8	8.9*

* Difference in 72 share less 58 share.

Source: Derived from Statistics Canada Publication No.'s 57-207 and 57-505.

The composition of energy consumption by source for the years 1958 and 1972 is shown in Table 2. This table reveals the volatility which is possible in the distribution of consumption as among fuel types. Both for Canada and Ontario, the most striking change is the decline of coal consumption to an almost insignificant share in both sectors. This rapid decline should be compared with the large increases in natural gas, in light fuel oil in the residential sector, and in light and heavy fuel oils in the commercial sector. Taken together, these three fuel types account for nearly three-quarters of energy consumption in each of the sectors. The predominance of these fuel types reflects the status of space heating (in commercial structures, space cooling as well) as by far the most important single class of end-use in these sectors. In addition, the decline in coal consumption and its replacement, primarily by natural gas, illustrates the difficulty of explaining energy consumption in terms of demand alone, since the increase in natural gas consumption has been due in considerable measure to increased availability.

Changes in the prices of fuels over time nevertheless help to explain the changing patterns of consumption. Table 3 shows the trends in price between 1958 and 1971 of the principal fuels employed in the domestic and commercial sectors. All fuels except coal decreased gradually in price in real terms, i.e., when deflated by a general price measure such as the Consumer Price Index (CPI). Natural gas, which has been most prominent in replacing coal, displayed the largest decline in real price by 1971, to only 72% of its level thirteen years

Table 2

Input BTU's

	Canada				Ontario			
	1958		1972		1958		1972	
	10^{12}BTU	%	10^{12}BTU	%	10^{12}BTU	%	10^{12}BTU	%
Domestic								
Coal	119.8	18.7	11.6	1.0	47.2	17.9	2.5	0.6
LPG	9.3	1.4	54.6	4.8	2.2	0.8	15.4	3.8
Kerosene	79.9	12.5	84.5	7.4	22.0	8.3	12.7	3.2
Diesel Fuel Oil	14.8	2.3	37.8	3.3	1.9	0.7	5.9	1.5
Light Fuel Oil	259.6	40.6	471.0	43.4	127.7	48.3	171.0	43.0
Heavy Fuel Oil	12.2	1.9	19.1	1.7	3.4	1.2	5.3	1.3
Natural Gas	78.9	12.3	281.1	24.8	30.2	11.4	117.0	29.4
Electricity	58.9	9.2	171.3	15.1	27.9	10.5	66.9	16.8
Other	5.8	0.8	0.5	-	1.4	0.5	-	-
Total	639.2	100.0	1131.5	100.0	263.9	100.0	397.1	100.0
Commercial								
Coal	39.9	21.4	5.0	0.6	28.4	41.6	4.2	1.3
Crude Oil	-	-	2.3	0.2	-	-	-	-
Kerosene	6.2	3.3	10.5	1.2	1.8	2.7	1.6	0.5
Diesel Fuel Oil	7.4	3.9	21.9	2.6	0.9	1.3	4.9	1.6
Light Fuel Oil	23.3	12.5	115.0	13.8	9.2	13.5	47.7	15.4
Heavy Fuel Oil	34.7	18.6	215.2	25.9	6.1	8.9	61.9	20.0
Natural Gas	38.0	20.3	266.1	32.1	6.3	9.2	113.7	36.7
Electricity	36.0	19.3	192.4	23.2	15.4	22.5	75.1	24.2
Other	0.9	0.4	0.3	-	0.3	0.4	0.4	0.1
Total	186.4	100.0	828.7	100.0	68.4	100.0	309.5	100.0

Sources: Ibid.

Table 3

Fuel Prices in Ontario: 1958-1971
($\$/10^6$ BTU)

	Oil[1]	Natural Gas[2]	Electricity[3]	Coal[4]	CPI(1961=100)
1958	1.057	1.360	3.898	-	0.968
1962	1.027	1.350	3.898	.4326	1.012
1966	1.087	1.350	3.898	.4345	1.114
1968	1.195	1.350	4.308	.4760	1.201
1970	1.255	1.350	4.308	.6205	1.297
1971	1.339	1.350	4.484	.7601	1.334
p71/p58	1.266	.992	1.150	1.757[5]	1.378
$\frac{p71 \times CPI58}{p58 \times CPI71}$	.918	.719	.834	1.275[5]	-

1. Retail price of home heating oil in Toronto
2. Price at rate of consumption of typical space heating customer.
3. Price at 500 KWH per month.
4. Price of coal in manufacturing sector.
5. 1971 relative to 1961.

previously. Its price in current dollars was constant over the entire period 1962-1971. Similarly the current price of electricity has changed in a series of steps, with levels then retained for several years. The price behaviour of both fuels reflects regulatory control rather than a decentralized response to market conditions.

Caution should be exercised in analyzing the figures of Table 3. Prices for oil, gas and electricity are intended to be representative for domestic consumers, but the price of coal is the industrial price. Therefore, only proportionate changes, rather than levels should be compared. It is the relative changes in price among fuels which are thought to determine inter-fuel substitution. The price of energy relative to all non-energy goods, the latter as represented in Table 3 by the CPI, is the appropriate measure of fuel price as an influence upon fuel consumption. The role of price is somewhat ambiguous, however, since not all fuels have been available to all consumers in all years, particularly in the case of gas. In addition, these prices are in terms of input BTUs.

Conversion of input BTUs to output BTUs can be accomplished by multiplication by a utilization efficiency factor. Such factors have been estimated at the federal Department of Energy, Mines and Resources (EMR) and are reproduced in Table 4. What is most striking are the disparities, both in the residential and commercial sectors, between coal and its major competitors for space heating. Thus, in order

Table 4

Utilization Efficiency Factors (%)

	Residential	Commercial
Coal	50	65
LPG	75	78
Still Gas	-	-
Kerosene	55	82
Diesel Oil	23	23
Light Fuel Oil	65	82
Heavy Fuel Oil	80	80
Natural Gas	75	78
Electricity	100	100

Source: Canadian Combustion Research Laboratories, Dept. of Energy, Mines and Resources

to yield the same energy output, coal would have to sell at a lower price per input BTU. In addition, requirements of handling, storage, etc., add to its real cost. At the other extreme, the nearly perfect efficiency of electricity could compensate for a large proportional difference in input price between it and other fuels.

By applying the estimates in Table 4 to input quantities of the various fuels we arrive at the aggregate efficiency estimates shown in Table 5. Change in efficiency over time may be decomposed into two factors: shifts among fuel types of differing efficiencies; and changes in the efficiency of utilization of each fuel type. Since the EMR efficiency estimates pertain to recent experience, only the former factor is represented.

It can be seen that there has been a substantial increase in overall efficiency in both sectors. In the domestic sector, efficiency in Ontario increased by the same 7% as Canada, while the Province's performance was somewhat better than the country's in the commercial sector. These increases, as should be evident from the preceding tables, stem primarily from the shift out of coal into natural gas and, in the commercial sector, into heavy fuel oil. It might be noted that we are limiting our attention to secondary consumption. Total BTUs consumed, including consumption by the energy conversion industry, to produce a BTU of output in these sectors might display significantly different trends. Investigation of this matter, however, is beyond the scope of the present study.

Table 5

Efficiency of Energy Utilization

	Canada		Ontario	
	1958	1972	1958	1972
Domestic				
1. input BTUs ÷ 10^{12}	639.2	1131.5	263.9	397.1
2. output BTUs ÷ 10^{12}	411.0	805.7	174.2	291.3
3. efficiency (2. ÷ 1.)%	64.2	71.2	66.0	73.3
Commercial				
1. input BTUs ÷ 10^{12}	186.4	828.7	68.4	309.5
2. output BTUs ÷ 10^{12}	145.4	683.5	53.1	257.9
3. efficiency (2. ÷ 1.)%	78.0	82.4	77.6	83.3

In Table 6, the consumption of energy in the Residential and Commercial Sectors in Ontario is shown in terms of output BTUs. Consequently, differences in efficiency of utilization cause a change in the distribution of fuels by share of the market. Electricity plays a greater role here than in the comparison on input terms, and the decline in share of light fuel oil in the residential sector is even greater.

Table 6 is not directly comparable with the preceding tables, however, because some additional adjustments have been made. Until now we have examined energy consumption in the domestic and commercial sectors. These designations correspond with the energy accounts compiled and published by Statistics Canada. The categories are defined by the individual fuel distributors, such as public utilities, rather than by the statistical agency. They therefore correspond only approximately with residential and commercial activities as these might be defined on economic grounds. The analysis of energy consumption patterns in Canada represented in the literature has been based upon the energy accounts without modification. In some cases, the sectoral breakdown has been treated as economically meaningful in the sense that the determinants of consumption in each sector have been measures of the economy to which the sectoral breakdowns nominally relate.

An illustration of how misleading the energy accounts data can be for analytical purposes is presented in Table 6.

Table 6

Ontario - Energy Consumption by Output BTU

	1958		1972	
	10^{12} BTU	%	10^{12} BTU	%
Residential				
Coal	23.6	14.6	1.2	0.4
LPG	1.6	1.0	11.5	3.9
Light Fuel Oil	78.8	49.0	105.6	35.9
Heavy Fuel Oil	2.7	1.6	4.2	1.4
Natural Gas	23.8	14.8	100.9	34.3
Electricity[1]	29.3	18.2	70.3	23.9
Total	160.8 (174.2)*	100.0	293.7 (291.3)*	100.0
% Growth	82.6 (67.2)*			
Commercial				
Coal	18.5	27.6	2.7	1.0
Kerosene[2]	13.6	20.2	8.2	3.2
Diesel Fuel Oil[3]	0.6	0.8	2.4	0.9
Light Fuel Oil[4]	11.8	17.6	44.7	17.4
Heavy Fuel Oil	4.9	7.3	49.5	19.3
Natural Gas	2.7	4.0	75.6	29.5
Electricity[1]	14.0	20.8	71.7	28.0
Total	67.0 (53.1)*	100.0	255.2 (257.9)*	100.0
% Growth	281 (385)*			

1. Includes net reallocation from commercial to domestic of 1.4×10^{12} BTU in 1958 and of 6.7×10^{12} BTU in 1972.

2. Includes reallocation from domestic to commercial of 12.1×10^{12} BTU in 1958 and 6.9×10^{12} BTU in 1972.

3. Includes reallocation from domestic to commercial of 0.4×10^{12} BTU in 1958 and 1.3×10^{12} BTU in 1972.

4. Includes reallocation from domestic to commercial of 4.2×10^{12} BTU in 1958 and 5.6×10^{12} BTu in 1972

Sources: Derived from Statistics Canada Publication No.'s 57-207 and 57-505.

*Official figures for domestic and commercial sectors as adjusted to output BTU's by Energy, Mines and Resources. See text p.12-13.

In that table, "Residential" is intended to pertain to all users associated with housing structures and their contents. "Commercial" continues to be a "catch-all" of users not included in Residential, Industrial or Transportation sectors, but now also includes non-residential farm uses, which are lumped with Domestic in the energy accounts. In order to produce Table 6 the following adjustments to the published figures were made. It must be stressed that while these adjustments seem plausible they are presented here merely as illustrative. Shifted from Domestic to Commercial to account for non-residential farm use were: all kerosene and diesel fuel oil and 5% each of light fuel oil and electricity reported as Domestic. Shifted from Commercial to Domestic were amounts equal to 10% of Domestic natural gas and electricity (net of adjustment for farm use) in 1958, and 15% of each in 1972. The latter adjustment is to account for the bulk metering of many apartment buildings, which are treated as commercial customers. The 15% figure is based upon a recent Ontario Hydro survey, while the lower 10% figure for 1958 is intended to account for the growth in proportion of apartment buildings since then. It is assumed that the effect of bulk metering upon the reported data for natural gas is the same as for electricity.

The totals for the individual years and the rate of growth are compared in Table 6, with the official figures for the "Domestic" and "Commercial" sectors as adjusted to output

BTUs by EMR. As a result of the adjustments a very different picture emerges of growth in consumption as between the two sectors. The growth of Residential consumption in output terms is nearly 83%, compared with 67% for Domestic, including farm, over the period 1958 to 1972. For the Commercial sector, the discrepancy is in the opposite direction and is even greater: 281% with corrections versus 385%. Accepting published energy consumption figures without modification for analysis and forecasting in relation to demographic and economic trends clearly involves great difficulties. For the purposes of this project, moreover, these results indicate that published figures cannot be used without a thorough examination of their construction, to provide control totals for estimates built up from detailed calculations.

An extrapolation of the growth trends developed above would yield projected figures like those shown in Table 7. Residential consumption is projected on the basis of a continuation of the historical growth in consumption per household. Commercial consumption is related to income (gross provincial product in real terms). Household and Income projections are consistent with one of the E.M.R. scenarios. The figures for residential consumption appear at least plausible, in the sense that a growth of nearly 200% over the next 30 years is not far out of line from a growth of over 80% in the preceding 15 years. The growth of

Table 7

Ontario Energy Consumption in the Domestic and Commercial Sectors:
Continuation of Past Trends

	(1) Residential Consumption (output BTUs $\div 10^{12}$)	(2) Households (thousands)	(3) Commercial Consumption (output BTUs $\div 10^{12}$)	(4) Gross Provincial Product ($\$ \div 10^{6}$) (constant 1961 $)
1958	160.8	1502	67.0	14,006
1972	293.7	2301	255.2	29,581
% Change 1958-1972	82.6	53	281	111
1986	517.7	3428	913	59,753
% Change 1972-1986	76.3	49	258	102
2000	855.9	4868	3270	120,701
% Change 1986-2000	65.3	42	258	102
% Change 1972-2000	191.4	111	1181	308

nearly 1200% versus less than 300% in the historical period in the commercial sector, however, seems improbably high, barring a drastic decline in energy prices over time, which is most unlikely. Other than yielding implausible results, this type of extrapolation leaves unanswered a number of questions about the magnitude of the effects of policy on growth, and questions of the "what-if" kind pertaining to economic and technological eventualities. Arriving at satisfactory answers to these questions involves the consideration of a number of issues, with some of the major ones listed here in terse form. Some of them have already been alluded to in the preceding chapter.

1. How sensitive to energy costs are the bases for forecasting demand themselves, i.e., number and size of households, extent of commercial space and value of provincial production?

2. How and to what extent do energy costs affect the configuration of new, and the modification of old structures and equipment?

3. How valid is past experience of energy utilization in an economy where price levels and relative prices may be well outside such experience?

4. To what extent are different fuels substitutable in particular end uses, and to what extent may technological change, spurred by prices, be expected to alter such substitutability?

5. Which of the current proposals for increasing efficiency are most likely to prove economic, and what will be the extent of the improvement?

6. To what extent can changes in attitude, i.e., conservation, be expected to decrease consumption over the long term, as contrasted with the ordinary demand response to price?

7. What will be the effects upon energy demand of changing production processes and location; urbanization; scale of production; specialization and separation of functions, e.g., administration and production; substitution between services provided at home and purchased in markets; etc.?

8. To what extent will consumers be willing to trade-off costs of fuel against costs of more efficient fuel-using structures and equipment?

While completely satisfactory answers to these and other important questions are beyond the scope of this study, the framework which has been developed should at least make it possible to introduce various sets of assumptions bearing upon them, based upon the information at hand, and to calculate estimates of their impacts.

Section Two

Section Two

Analysis of Technical Factors Affecting Residential Energy Consumption

Final Report
Section Two

For: Ontario Ministry of Energy

Date: March 23, 1977
Revised, November 1, 1977

FOREWORD

This document is part of a report on the results of an analysis of residential and commercial energy demand in Ontario. The work was conducted under a contract between the Ministry and Informetrica Limited, which was assisted by the Energy Research Group of Carleton University. The objective of the study is to improve the ability of Ministry staff to examine energy-related policy issues by allowing them to make soundly-based quantitative estimates of changes in fuel demand patterns by end use.

Michael McCracken of Informetrica Limited exercised overall direction of the project. Principal investigator for Informetrica Limited was Irving Silver, Senior Advisor. He was assisted by Paul Jacobson, Senior Economist. Principal investigators for the Energy Research Group were Professors J.T. Rogers and David Moizer and Mr. Bruce Findlay. They were assisted by Messrs. Rick Moll, Michael Swinton and A. Abdelkerim.

EXECUTIVE SUMMARY

Section Two: Analysis of Technical Factors Affecting Residential Energy Consumption

This section describes the methods used in calculating the residential energy requirements for Ontario on a per dwelling basis. It consists of two chapters.

Chapter 1 describes:

(1) the calculation of output energy requirements of fixed equipment and;

(2) the approach used for the analysis of appliances.

Chapter 2 describes in detail how the variables were calculated for each of four end-uses:

(1) Space Heating;

(2) Water Heating:

(3) Space Cooling; and

(4) Appliance Utilization.

Within each end-use category, the analysis consists of a description of the:

(1) Method used to establish demand;

(2) Results;

(3) Efficiencies; and

(4) Technological Change.

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LIST OF SYMBOLS

A	Area of building component, ft^2
ACD	Number of operating space cooling days
ALIV	Livable area, ft^2
C_p	Specific heat of air, Btu/lbm ^oF
CONV	Fuel heating value conversion factor
COP	Coefficient of performance
DD	Degree-days, ^oF day
DETD	Design equivalent temperature difference, ^oF
EDD	Equivalent degree-days, ^oF day
EER	Electrical efficiency ratio, Btu/Watt-hr
EH	Seasonal heating efficiency, %
FCL	Perimeter cooling load, Btu/hr
FCONH	Fuel consumption, gallons, cu.ft. or kWh/dwelling yr
FCONHA	Fuel consumption for space cooling, kWh/dwelling yr
FCONW	Fuel consumption for hot water heating, gallons, cu.ft. or kWh/dwelling yr
H*	Total rate of heat gain from sources other than the heating system, Btu/hr
H^*_{app}	Rate of heat gain from appliances, Btu/hr
H^*_{sol}	Rate of heat gain from solar radiation, Btu/hr
H^*_W	Rate of heat gain from wild heat, Btu/hr
H_f	Rate of heat delivery by heating system, Btu/hr
HFAB	Perimeter heat loss, Btu/hr ^oF
HINF	Infiltration heat loss, Btu/hr ^oF
HL	Rate of heat loss, Btu/hr
ICL	Infiltration cooling load, Btu/hr
IH	Input energy requirements for space heating, MMBtu/dwelling yr
IHA	Input energy requirements for space cooling, MMBtu/dwelling yr
IW	Input energy requirements for water heating, MMBtu/dwelling yr
K	Heat loss factor, Btu/hr.^oF
k	Extinction coefficient for solar radiation in glass, cm^{-1}
l	Window glass thickness, cm

MAX	Mean maximum yearly temperature, $^{\circ}F$
MIN	Mean minimum yearly temperature, $^{\circ}F$
OH	Output energy requirements for space heating, MMBtu/dwelling yr
OHA	Output energy requirements for space cooling, MMBtu/dwelling yr
OW	Output energy requirements for water heating, MMBtu/dwelling yr
q_1^w	Total heat gain rate through windows in summer, Btu/hr ft^2
R	Thermal resistance of insulation,(Btu/hr ft^2 $^{\circ}F)^{-1}$
RR	Common thermal resistance, (Btu/hr ft^2 $^{\circ}F)^{-1}$
SHGF	Solar heat gain factor, Btu/hr ft^2 of window
$\overline{SHGF}$	Heating-season average solar heat gain factor, Btu/hr ft^2 of window
SRL	Solar radiation cooling load, Btu/hr
T*	Balance temperature, $^{\circ}F$
T_I	Inside temperature, $^{\circ}F$
T_{max}	Maximum hot water temperature, $^{\circ}F$
T_{min}	Minimum hot water temperature, $^{\circ}F$
T_o	Outside temperature, $^{\circ}F$
$T_{o,av}$	Summer design temperature, $^{\circ}F$
T_{SI}	Summer indoor design temperature, $^{\circ}F$
ΔTAPP	Temperature rise due to wild heat, $^{\circ}F$
ΔTSOL	Temperature rise due to solar radiation, $^{\circ}F$
U	Overall heat transfer coefficient, Btu/hr ft^2 $^{\circ}F$
V	Internal volume, ft^3
W_i	Hot water consumption, lb_M/hr, by dwelling type i
WA	Window area, ft^2
X_i	Average number of persons per dwelling type i
YAV	Yearly average temperature, $^{\circ}F$
ZI	Average height of ceiling, ft
η	Average number of air changes per hour, hr^{-1}
ρ	Inside air density, lbm/ft^3
τ	Number of operating hours
ψ	Latitude angle, degrees

Subscripts

i	Dwelling type classification
j	Dwelling age classification
k	Building component classification
ℓ	Dwelling location classification
n	Fuel type classification

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INTRODUCTION

This volume describes the methods used in calculating the yearly residential energy requirements of characteristic dwelling types in Ontario. The yearly energy intensities per dwelling derived herein are used by the Residential Demand Model, described in volume 1, to calculate overall residential energy requirements for the Province of Ontario.

The analysis presented here considers two classes of energy-using equipment. These are

(1) Fixed equipment; and

(2) Movable equipment.

In the category of fixed equipment the energy requirements for

(1) Space heating;

(2) Hot water heating; and

(3) Space cooling

are analyzed. The approach taken in this category was to estimate the theoretical output energy requirements by modelling the characteristics of energy demand. The input energy requirements (energy consumption) were then calculated by establishing conversion efficiencies. These were derived through analysis of the technical characteristics of energy-using equipment.

In the category of movable equipment, i.e. appliances, the energy <u>input</u> requirements (rather than output requirements) were established from published data.

This volume consists of two chapters. Chapter 1 describes:
(1) the overall framework of a computer program designed to calculate the output energy requirements of fixed equipment; and
(2) the underlying approach used for the analysis of appliances.
Chapter 2 describes in detail how the variables were calculated, and includes discussions on the reliability of the results obtained. This chapter consists of four sections which cover:

(1) Space Heating;

(2) Water Heating;

(3) Space Cooling; and

(4) Appliance Energy Utilization.

Within each section (energy end-use category) the analysis consists of a description of the

(1) Method used to establish demand;

(2) Results;

(3) Efficiencies; and

(4) Technological Change.

Throughout this volume reference will be made to the Fortran code names used to describe the variables of the Residential Energy Demand Model.

1.0 APPROACH

1.1 FIXED EQUIPMENT ENERGY DEMAND

A program was developed to calculate:

(1) the output energy requirements for space heating by type of building i, age j, region ℓ and fuel type n($OH_{ij\ell n}$). (This corresponds to Step 3 of the Residential Demand Model described in Volume 1)

(2) the output energy requirements for water heating by i, j, ℓ and n($OW_{ij\ell n}$). (This corresponds to Step 5 of the overall model (Volume 1))

and (3) the output energy requirements for central space cooling by i, j, ℓ and n($OHA_{ij\ell n}$). (This corresponds to Step 6 of the overall model (Volume 1)).

CLASSIFICATION OF VARIABLES

For the calculation of the variables OH, OW, OHA the classifications i, j, ℓ and n are given by:

	1	2	3	4
Type (i)	Single detached	Semi-detached and duplex	Row	Apartment
Age (j)	Pre-1966	1966-70	1971-75	1976 & later
Region (ℓ)	Eastern (Ottawa)	Central (Toronto)	South-western (Windsor)	Northern (Thunder Bay)
Energy Supply (n)	Non-electric	Electric		

The choice of these classifications was based on: (1) building thermal characteristics; and (2) available Housing Stock data classifications.

Each classification will be discussed.

(1) Type (i). The Statistics Canada classification [1] is:

(a) Single detached - a structure with only one dwelling;

(b) Single attached - includes dwelling units separated by a common wall. In this category, structures which have only two units are classified as single attached (double) and all others are single attached (other). These include row houses.

(c) Apartment or flat - These dwellings are subdivided into two categories: (i) duplex - when a structure is divided into two dwellings which are on top of each other; (ii) all dwellings of the apartment or flat-type other than the duplex type.

On the other hand, the CMHC Housebuilders Survey classification [2] is

(a) Single detached - same as Statistics Canada.

(b) Semi-detached and duplex - these correspond with Statistics Canada single attached (double) and apartment (duplex) respectively.

(c) Row - corresponds to Statistics Canada single attached (other).

(d) Apartment - corresponds to Statistics Canada apartment (other).

For this study the CMHC classification was used since data were available on the physical characteristics of these types. The thermal characteristics of each category were sufficiently homogeneous to allow a unique energy analysis for each category.

(2) Age (j). The age groups were selected on the basis of the changes in Insulation Standards [3]. Standards changed in 1965, 1970 and 1975. The residential model operates with a time step of five years.

(3) Region (ℓ). Regional variation in weather conditions (degree-days) results in variation in insulation standards [3]. The four regions used are:

(1) Ottawa (Eastern, 1 & 2)

(2) Toronto (Central, 3 & 4)

(3) Windsor (Southwestern, 5 & 6)

(4) Thunder Bay (Northern, 7).

The classification in brackets shows the regions (defined in The Residential Demand Model, Volume 1) which are characterized by the cities chosen for this analysis. These four regions have a significant range of average degree-days.

(4) Energy Supply (n)*. A classification of non-electric and electric is used since the insulation standards for these two groups are different. For convenience, this classification will hereafter be designated "fuel type".

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* The subscript "n" in this volume corresponds with "m" in volume 1, where it refers to "heat-loss class".

The analysis of output energy requires only an electric/non-electric split. However, the analysis of input energy requires a further disaggregation to reflect the different "non-electric" fuels - i.e. oil and gas.

DESCRIPTION OF THE MAIN PROGRAM

The main program, MAIN, as illustrated by the flow chart (Fig.1) organizes:

(1) data entry which is common to the subroutines HTLOSS and AIRCON. Tables 1 to 4 describe these data. An explanation of the development of the data is given in Chapter 2.

(2) the intermediate calculation of the output energy requirements for space heating (Step 3 of the model) given by

$$OH_{ij\ell n} = 24\ K_{ij\ell n}\ EDD_{ij\ell n} \qquad (1.1)$$

where

24 = hours in a day

$K_{ij\ell n}$ = heat loss factor for each dwelling by type (i), age (j), region (ℓ) and fuel type (n), Btu/hr$^{\circ}$F

$EDD_{ij\ell n}$ = equivalent degree-days as a function of (i), (j), (ℓ) and (n).

The heat loss factor K is calculated in subroutine HTLOSS and the equivalent degree-days are calculated in subroutine EQUIVDD. The detailed descriptions of these routines are given in Chapter 2.

(3) the calculation of $OHA_{ij\ell n}$ - the output energy requirements for central space cooling by (i), (j), (ℓ) and (n). This calculation is performed in subroutine AIRCON. The penetration of central air conditioning in the 1975 building stock is estimated [4] at 4-5%. It was considered necessary, though, to include the calculation of OHA for the purposes of projection since it is expected that considerable growth in this end-use will occur in the future.

(4) the calculation of OW_{ijn}, the output energy requirements for water heating by (i), (j) and (n). This calculation is performed in subroutine HWATER.

(5) the program output which includes:

(a) $OH_{ij\ell n}$, the output energy requirements for space heating by type of dwelling (i), age (j), region (ℓ) and fuel (n). (See Table 11);

(b) $OHA_{ij\ell n}$, the output energy requirements for central space cooling by (i), (j), (ℓ) and (n). (See Table 25);

(c) $OW_{ij\ell n}$, the output energy requirements for water heating by (i), (j), (ℓ) and (n). (See Table 19).

1.2 MOVABLE EQUIPMENT ENERGY DEMAND

The calculation for the energy demand of movable equipment consists of establishing the following: saturation; capacity in terms of appliance output; utilization factor which characterizes the typical use of the device; and the efficiency which converts output energy requirement to input. This formulation is consistent with the fixed equipment model, and it permits the investigation of change in appliance use, popularity and technological innovation. However, unlike the cases of the calculation of space heating, water heating, and air conditioning energy requirements, there is no analytical approach to calculate the theoretical energy output of most appliances. For such appliances, pseudo-efficiencies and corresponding pseudo-outputs will be defined in order to be consistent with the model structure. This will permit the modelling of change in appliance performance by specifying "efficiency" changes, as with the fixed equipment. A second operation groups appliances of similar characteristics to simplify the projection task described in volume 1. A detailed description of these steps is given in the next chapter.

For convenience, lighting is included in this class.

2.0 ENERGY ANALYSIS

2.1 SPACE HEATING

The derivation of space heating energy requirements for the characteristic dwelling types described above is a three-step procedure: the modelling of annual heating energy requirements, determination of heating system efficiency, and the calculation of the resulting fuel requirements. A discussion of the various modelling methods for determining annual heating requirements, and a description of the model developed and used in this study are presented here. Also included is a detailed discussion of furnace system efficiencies and a presentation of resulting annual fuel requirements by dwelling type.

2.1.1 Degree-Day Method

The well-known degree-day method [5] for determining the total annual heat output required from a heating system is developed as follows. Heat is lost from a building by:

(1) transmission through walls, roof, floor and the basement (perimeter heat loss); and

(2) infiltration of air (infiltration heat loss).

For steady-state conditions, the rate of heat loss, HL, is given by:

$$HL = K\,(T_I - T_o) \tag{2.1}$$

where T_I = Temperature inside the building, ^oF

T_o = Ambient temperature, ^oF

K = Overall heat loss factor for the building, Btu/hr^oF.

The value of K depends on the two components of heat loss, namely perimeter and infiltration heat loss, as shown in equation 2.2.

$$K = \sum_{k=1}^{8} A_k U_k + \eta \rho C_p V \tag{2.2}$$

where

A_k = area of building component k, ft^2

U_k = overall heat transfer coefficient of component k, Btu/hr ft^2 ^oF

η = average number of air changes per hour, hr^{-1}

ρ = inside air density, lbm/ft^3

C_p = specific heat of air, Btu/lbm ^oF

V = internal volume of residence, ft^3

By increasing the insulation level the value of U decreases and this reduces the heat loss coefficient. This causes a reduction in the amount of heat loss from a building.

Part of the heat loss is made up by the heat that is generated by electric lights, household appliances, heat losses from water heaters and from people who occupy the dwelling. This is called "internal heat gain" or "wild heat". In addition, solar energy enters the house, mainly through the windows (solar gain). Therefore the difference between the rate of heat loss HL and the inherent rate of supply H* (wild heat + solar heat) is supplied by the heating system.

Thus

$$H_f = HL - H^* \tag{2.3}$$

where H^* = total rate of heat gain from sources other than the heating system, Btu/hr

H_f = rate of heat delivered by the heating system, Btu/hr

The heating system operates only when

$$HL > H^*$$

or using equation (2.1) when

$$K(T_I - T_o) > H^*$$

from which the following condition holds

$$T_o < T_I - \frac{H^*}{K} \tag{2.4}$$

Therefore heating is required only when the outside temperature T_o falls below $T_I - \frac{H^*}{K}$.

Let the outside temperature below which the heating system comes into action be designated by T^*.

Thus
$$T^* = T_I - \frac{H^*}{K} \tag{2,5}$$

or
$$H^* = K(T_I - T^*) \tag{2.6}$$

which when substituted into (2.3) and (2.1) gives the rate of heat output required from the heating system, H_f.

Thus

$$\begin{aligned} H_f &= K(T_I - T_o) - K(T_I - T^*) \\ &= K(T^* - T_o) \end{aligned} \tag{2.7}$$

The total energy required for heating is therefore:

$$\int H_f dt = K \int (T^* - T_o) dt$$

where the integrals are taken over the heating season.

The degree-day method of estimating heating requirements involves approximating

$$K\int (T^* - T_o) dt \text{ by } 24 \text{ K DD}$$

where

$$DD = \int (T^* - T_o) dt$$

is the number of heating degree-days.

2.1.2 The Equivalent Degree-Day Method

Conventionally in North America, the balance temperature, T*, is taken as $65^{\circ}F$ ($18.3^{\circ}C$) and values of degree-days, D_d, based on this balance temperature and determined from meteorological data averaged over many years, are available for most localities. The choice of $65^{\circ}F$ as the balance temperature recognizes that solar gains and "wild heat" from appliances, equipment and occupants play a role in establishing the heating requirements of a building, since the normal internal heating season design temperature is about 70 to $72^{\circ}F$.

However, it appears that the use of an arbitrary fixed balance temperature of $65^{\circ}F$ is not an adequate approximation for modern, well-insulated "tight" residential buildings, equipped with a conventional range of appliances. The over-estimation of the annual heating load by the conventional degree-day method can be attributed mainly to this assumption of a fixed balance temperature. To provide the accuracy desirable in the present forecasting model, a method has been developed which, in effect, permits the calculation of an appropriate balance temperature allowing for the heating season average solar gain for the housing stock classification used, and for the heating season average wild heat.

Thus, rather than fixing T* at an arbitrary value, a "floating" value of balance temperature is calculated in the following manner:

Let H*, the total rate of heat gain from sources other than the heating system, be denoted by:

$$H^* = H^*_{sol} + H^*_W \tag{2.8}$$

where

H^*_{sol} = Rate of heat gain from solar radiation, Btu/hr

H^*_W = Rate of heat gain from wild heat (lighting, appliances, heat losses from water heaters and occupants), Btu/hr.

Then the outside temperature T* below which the heating system operates is given by

$$T^* = T_I - \frac{H^*_{sol}}{K_{ij\ell n}} - \frac{H^*_W}{K_{ij\ell n}} \qquad (2.9)$$

Estimates of H^*_{sol} and H^*_W are calculated (Section 2.1.4) so that a new balance temperature is obtained. The equivalent degree-days can then be calculated from:

$$EDD = \int (T^* - T_o)dt \qquad (2.10)$$

where T^* is given by equation 2.9, rather than being fixed at 65°F. It will be seen from sections 2.1.3 and 2.1.4 that the equivalent degree-days are a function of type of dwelling i, regional location ℓ, age j and fuel type n, since T^* is now a function of these classifications.

2.1.3 Calculation of the Heat Loss Factor

A diagram of the subroutine used to calculate the heat loss factor, $K_{ij\ell n}$, is shown in Figure 2.

$K_{ij\ell n}$ consists of two components, namely the perimeter heat loss factor, HFAB, and the infiltration heat loss factor, HINF.

Therefore

$$K_{ij\ell n} = HFAB_{ij\ell n} + HINF_{ijn} \qquad (2.11)$$

where

$$HFAB_{ij\ell n} = \sum_{k=1}^{8} A_i^k \; U_{ij\ell n}^k$$

and

A_i^k = area of building component k of house type i, ft^2

$U_{ij\ell n}^k$ = overall heat transfer coefficient of building component k, by type i, age j, region ℓ and fuel n, Btu/hr ft^2 °F

and

$$HINF_{ijn} = \eta_{jn} \, \rho \, C_p \, V_i \qquad (2.12)$$

η_{jn} = number of air changes per hour by age j and fuel n, hr^{-1}

ρ = house air density, 0.075 lbm/ft^3

C_p = specific heat of air, 0.24 Btu/lbm ^oF

V_i = volume of building, ft^3

Construction of Variables

Perimeter Heat Loss

(i) $HFAB_{ij\ell n}$ - The total perimeter heat loss is calculated by consideration of eight building perimeter components k. Each component, $HHFAB^k_{ij\ell n}$, is given by:

$$HHFAB^k_{ij\ell n} = A^k_i \; U^k_{ij\ell n}$$

The following perimeter components are included in the analysis:

1 Ceiling

2 Exterior wall

3 Foundation wall above grade

4 Foundation wall below grade

5 Windows

6 Doors

7 Floors above a crawl space

8 Basement slab.

(ii) The areas A^k_i of building component k in dwelling type i were obtained from the 1969 CMHC House Builders Survey [2]. These are given in Table 1. These areas are averaged for the housing stock given in reference [2].

(iii) The overall heat transfer coefficient for each building component k is calculated from:

$$U^k_{j\ell n} = \frac{1}{RR^k + R^k_{j\ell n}} \qquad (2.13)$$

where

RR^k = common thermal resistance of component k, $(\text{Btu/hr ft}^2\ {}^oF)^{-1}$

and

$R^k_{j\ell n}$ = thermal resistance of the insulation added to the building component k, by j, ℓ and n, $(\text{Btu/hr ft}^2\ {}^oF)^{-1}$

The common thermal resistances, RR^k, used are as follows*

RR^1: Ceiling		Thermal Resistance, $(\text{Btu/hr}^2\ {}^oF)^{-1}$
Attic surface films		0.25
1/2" gypsum wallboard		0.45
Inside surface film		0.61
	Total	1.31
RR^2: Exterior Wall		
Outside surface film		0.17
Face brick siding		0.42
Building paper		0.06
7/16" fibreboard		1.04
Air space		0.97
1/2" gypsum wallboard		0.45
Inside surface film		0.68
	Total	3.79
$RR^{3\&4}$: Foundation Wall**		
8" Concrete		1.11
Internal air films (still)		0.68
External air films (15 mph)***		0.17
	Total	1.96

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* The thermal resistance, R_t, is the reciprocal of the thermal conductance, C_t, i.e., $R_t = \frac{1}{C_t}$. The thermal conductance for any thickness can be obtained by dividing the thermal conductivity, k, by the thickness in inches, n, i.e., $C_t = k/n$ Btu/hr ft^2 ^oF. Typical values for C_t and k can be found in [6]. For components 5, windows, and 6, doors, see Table 3b.

** See page 16, section v, for treatment of below-grade areas.

*** For above-grade area only.

RR^7: Floor over Crawl Space

Crawl space surface film		0.25
5/8" plywood		0.63
Floor tile		0.05
Inside surface film		0.92
	Total	1.85

RR^8: Basement Floor**

Inside surface films		0.92
Floor tile		0.05
	Total	0.97

In 1969 and 1974 CMHC conducted Housebuilders Surveys.* The 1969 survey (Material Input Survey) [2] examined in detail the physical characteristics of each building component (e.g. walls, ceilings, floors, etc.) by house type (single detached, semi-detached, row house and apartment). The insulation levels of each component were recorded. The 1974 Housebuilders Survey was not as detailed. The information was given in the form of saturation statistics and did not give data by dwelling type. Due to the detail of the 1969 survey these data were used for the model houses in the energy analysis. However, comparison of the 1969 and 1974 survey revealed that each of the four types of dwellings used similar materials in both survey years. Due to insufficient data on the pre-1966 housing stock, construction practice as outlined in the 1969 survey was assumed to apply to the pre-1966 housing stock. This refers specifically to materials other than insulation. Of course, many pre-1966 houses were not constructed within the modern "frame" construction standards. Without a data base on this age group of dwellings, a separate analysis cannot be made. In summary, the energy analysis is oriented towards the modern frame house construction. Since the model is intended for forecasting purposes this deficiency will not be a major one, and will become less important for longer-term forecasts. Variation in the thermal characteristics of

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* These surveys were representative samples of all new construction in 1969 and 1974 respectively.

** See page 20, section v, for treatment of below-grade areas.

houses due to age is reflected in the insulation levels added and in different air leakage characteristics.

(iv) The thermal resistances $R^k_{j\ell n}$ of the insulation added to each building component k by j, ℓ and n are given in Tables 2a and 2b.

These insulation levels are derived from the 1965, 1970 and 1975 Canadian Codes for Residential Construction [3]. The codes give the overall minimum thermal resistance required for each building component by degree-day range and for electrically and non-electrically heated dwellings. It is realized, however, that the National Building Code is only a guide to which builders need not adhere. It was necessary, therefore, to use judgement as to the actual insulation levels used. It is noted that Tables 2a and 2b give the insulation levels for different regions (ℓ), age of building (j) and fuel equipment type (n). No variation in insulation with the type i of dwelling is included. However, the program is designed to allow for this variation if required.

(v) The basement wall below grade and the basement floor overall heat transfer coefficients were obtained from data developed by the Division of Building Research of NRC [7] and are given in Table 3b.

These coefficients are based on the overall temperature difference from the interior to the ambient air, as explained in reference [7].

(vi) Allowance is made in the calculation of $U^k_{ij\ell n}$ for those building components k which have wood studs, rafters or joists, by assuming that these elements occupy 15% of the area of the component. For example, the overall heat transfer coefficient for the ceiling is calculated by:

$$U_{ceiling} = \frac{0.85}{(1.31 + R_{ins})} + \frac{0.15}{(1.31 + R_{wood})}$$

where 1.31 = Common thermal resistance of ceiling, $(\text{Btu/hr ft}^2\ {}^{\circ}\text{F})^{-1}$

R_{ins} = Thermal resistance of insulation added between rafters, $(\text{Btu/hr ft}^2\ {}^{\circ}\text{F})^{-1}$

R_{wood} = Thermal resistance of 3 1/2" rafter, $4.37\ (\text{Btu/hr ft}^2\ {}^{\circ}\text{F})^{-1}$

The overall heat transfer coefficients for the walls and floors above a crawl space are calculated in a similar manner. Where insulation is applied to an exterior wall, its thermal resistance replaces that of the air space in the component resistances.

Infiltration Heat Loss

The greatest uncertainty in determining K is the choice of the number of air changes per hour, η. This depends on many factors including window and door crack lengths, type of windows and doors, house structure, wind velocity and direction, internal to external temperature differences, existence or not of fireplaces, type of heating (electric or non-electric), furnace operation, ventilation fan operation and habits of residents [6,8,9,10,11]. Thus, the determination of a heating-season average value of η characteristic of the various residence types is very difficult. Although new houses, particularly electrically-heated ones, may have as low as 0.2 to 0.4 air changes per hour, older houses may have values between 0.5 and 0.8. Because of the many uncertainties, a value of 0.5 air changes per hour was used in the model for non-electrically heated houses, and 0.3 for electrically heated houses, for all vintages. The program, however, permits the specification of η at any desired value. This feature was used to evaluate the sensitivity of the total seasonal heating demand to infiltration rate. The results, as reported in reference [12], show that seasonal heating demands, for single detached houses, vary over a range of about 20% only, for infiltration rates varying from 0.2 to 0.5 air changes per hour.

Variation in the infiltration heat loss by type of dwelling i is introduced via the different internal volumes, V_i.

The volume of the dwelling V_i is calculated from:

$$V_i = ALIV_i \ (Z1) \tag{2.14}$$

where

$ALIV_i$ = Livable area of dwelling type i (Table 1)

$Z1$ = Effective height of ceiling*, 7'6"

Outputs from this routine include:

1) Component fabric heat loss, HHFAB, for each building component k by i, j, ℓ and n, Btu/hr ^oF
2) Areas A_i^k (ft^2) and overall heat transfer coefficients $U_{ij\ell n}^k$, Btu/hr ft^2 ^oF
3) Total perimeter heat loss factor, HFAB by i, j, ℓ and n, Btu/hr ^oF
4) The infiltration heat loss factor, HINF by i, j and n, Btu/hr ^oF
5) The heat loss factor $K_{ij\ell n}$ by i, j, ℓ and n, Btu/hr ^oF (See Table 6).

The analysis ignores any latent heat load imposed by the infiltrating air since this will generally be a small fraction of the total heat load. Any error introduced by this assumption will be within the uncertainty resulting from the estimate of the infiltration rate.

2.1.4 Calculation of the Equivalent Degree-Days

The equivalent degree-days, EDD, are a function of dwelling type i, age j, regional location ℓ and fuel type n.

A diagram of the sub-routine used for this calculation is shown in Figure 3. The steps are:

(i) Calculate the heat gain rate due to solar radiation, H^*_{sol} Btu/hr

(ii) Calculate the heat gain rate due to wild heat, H^*_W, Btu/hr

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* The effective height is the estimated height that will yield the actual air volume of the household. It accounts for the fact that closets, walls, furniture, carpets, etc. occupy part of the total volume. Thus, the effective height for infiltration calculations is less than the height used for wall heat transfer calculations (i.e. about 8 ft).

(iii) Determine the balance temperature, T^*, ^oF

(iv) Calculate the equivalent degree-days, EDD, ^oF DAY.

From equation 2.9, T^*, the balance temperature, may be written as

$$T^*_{ij\ell n} = T_I - \frac{H^*_{sol,i\ell}}{K_{ij\ell n}} - \frac{H^*_{W,i}}{K_{ij\ell n}}$$

where T_I = inside temperature, ^oF. A value of 72^oF was used. However, this is included as a variable so that parameter studies may be done. See footnote, p.26

$H^*_{sol,i\ell}$ = solar heat gain rate through the windows by type of dwelling i and regional location ℓ, Btu/hr

$H^*_{W,i}$ = wild heat gain rate by i, Btu/hr

$K_{ij\ell n}$ = heat loss factor by i, j, ℓ and n, Btu/hr ^oF.

Heating-season average solar heat gain rate, $H^*_{sol,i\ell}$

Calculations of solar contributions to space heating or cooling are greatly facilitated by the use of tables of solar heat gain factors (SHGF) [6,13]. Solar heat gain factors are the instantaneous rates of solar heat transfer on a clear day through a unit area of one layer of unshaded double-strength sheet glass at a given location, month of year, time of day and orientation of surface.

In the present study, solar heat gain factors from reference [13] were used. The SHGF's from reference [13] are given for an average clear day (Clearness Number = 1.0 [14]), and allow for direct, scattered and ground-reflected radiation. The direct component allows for annual variations of the solar constant and the atmospheric extinction coefficient. The diffuse component allows for the seasonal variation of scattering in the atmosphere and accounts for the diffuse radiation incident on a vertical surface by the empirical equation of Threlkeld [15]. The ground-reflected component assumes a ground reflectivity of 0.2. The window glass assumed in the table has a value of kl, i.e., the product of extinction coefficient and glass thickness, equal to 0.05, which is typical of window

glass used in North America [13]. The glass is also assumed to have an index of refraction of 1.52.

Note that the model used in the study assumes that all solar heat gains occur through windows. While this is not rigorously true since solar radiation will increase the outer surface temperatures of opaque walls and roofs, thus reducing the heat loss rate, the magnitudes of such effects are considerably less than those of solar heat gains through windows [16] and are ignored in this study.

The heating-season average solar heat gain rate was determined in the following manner. For a given latitude the tables of reference [13] give daily total SHGF's for a typical day of each month on vertical surfaces oriented in eight directions (N, NE, E, SE, S, SW, W, NW). For a given latitude, the daily totals were averaged over the day and over the eight directions, it being assumed that the housing stock in Ontario is randomly oriented. The resulting directional-average value of SHGF was then assumed to represent also a time-average value for the month in question. This process was repeated for each month of the heating season, which, in Ontario may be assumed to extend from the end of September to the end of March, and the resulting values averaged to find the heating-season average solar heat gain factor for a given latitude. This procedure was repeated for a number of latitudes over the range of $43^{\circ}N$ to $49^{\circ}N$, which covers the latitudes of interest in this study, that is, those within which the majority of the population of Ontario lives. The resulting heating-season average solar heat gain factor was found to be a linear function of latitude and an equation representing it was established by the least-squares technique:

$$\overline{SHGF} = 50.5 - 0.481\psi \qquad (2.15)$$

$$43^{\circ}N \leq \psi \leq 49^{\circ}N$$

Since almost all of the Ontario housing stock is equipped with double-glazed windows, the model assumes that double-glazing is standard. Therefore, the above heating-season average solar heat gain factor must be modified to allow for double-glazed windows. The conventional approach to

allow for such factors is to employ shading coefficients [6,13]. For example, the shading coefficient for a double-glazed window of ordinary window glass is 0.9 [6]. That is, to calculate the solar heat transfer through a double-window, the appropriate solar heat gain factor is multiplied by 0.9. However, the shading coefficient is designed to establish the maximum heat gain rate resulting from the particular configuration, since the main use of shading coefficients is to establish design heat loads for cooling systems, while what was needed for our purposes was a heating-season average value.

To establish a value for the heating-season average shading coefficient, the following procedure was used. The incidence angles for direct solar radiation for vertical windows with various orientations at various times of the year were established as a function of time of day using solar altitude and azimuth angles given in reference [13]. Then, taking values of transmissivity of ordinary window-glass as a function of incidence angle from tables in reference [17], the reduced solar heat gain because of the second sheet of glass was calculated as a function of time of day by multiplying the solar heat gain factor for the chosen orientation from reference [13] by the appropriate transmissivity. The resulting reduced daily total solar heat gain factor was divided by the normal daily solar heat gain factor from reference [13] to establish an average shading coefficient for the day. By repeating this procedure for various window orientations and times of year, a heating-season average shading coefficient for double-glazed windows was established as 0.8.

An allowance must also be made for the presence of blinds or curtains on the windows. Values of shading coefficients for blinds of various types and for curtains are available [6], but again these would give the maximum solar heat loads for such components rather than heating-season average values. For example, for light-coloured venetian blinds on a double-glazed window, the shading coefficient is 0.51 [6]. Reducing this value in proportion to the reduction in the value for a double-glazed window alone, an estimated heating-season average value is about 0.45. Of course, there is no way of actually determining the number of windows in the Ontario housing stock that will be equipped with blinds and curtains nor the

percentage of time during the heating season that the blinds and curtains will be closed. Therefore, there is no justification for attempting to develop a very elaborate model for the windows. It was thus assumed that one-third of the windows would have closed blinds or curtains at any one time, so that using the above estimated values, the overall correction factor for the heating-season average solar heat gain factor was estimated to be 0.68. This correction factor was assumed to apply in each of the regions of the Province used in the model.

An additional correction to the heating-season average solar heat gain factor is required for the effects of cloud cover. A correlation for the overall effect of cloud cover on direct and diffuse solar radiation is given by Kimura and Stephenson [18], but this correlation could not be used because of lack of information on typical cloud covers in the various regions of the province. However, data extending over a period of 23 years were available for the monthly-average solar irradiation on a horizontal plane in the Ottawa region [19]. These data were compared to the monthly-average values of solar insolation for a clear day on a horizontal plane calculated from data given in reference [13], and the ratios of the two values were taken as representing the monthly-average effects of cloud cover. The monthly-average values were then averaged to determine the heating-season average value. The heating-season average correction factor for cloud cover determined in this way was 0.67. Lacking any other information, it was assumed that this correction factor applied in all the regions of the Province.

Therefore, the modified value of solar heat gain factor which allows for double-glazed windows, blinds and curtains and cloud cover is given by:

$$\overline{SHGF}_c = (0.68)\ (0.67)\ (50.5 - 0.481\psi) \tag{2.16}$$

$$= 23.0 - 0.219\psi \text{ Btu/hr ft}^2 \text{ of window area, distributed evenly in all directions.}$$

It can be easily shown that the heating-season average solar heat gain factor is related to the heating-season average solar heat gain rate, $H^*_{sol,i\ell}$ by:

$$H^*_{sol,i\ell} = (\overline{SHGF_c})\, WA_i \qquad (2.17)$$

Therefore, the heating-season average solar heat gain rate is given by:

$$H^*_{sol,i\ell} = (23.0 - 0.219\psi)\, WA_i \qquad (2.18)$$

There are several other factors which can affect the heating-season average solar heat gain rate which are not accounted for in equation 2.18. These factors include the effects of adjacent buildings, trees, topographical features and other objects on solar radiation. These effects include reductions in solar heat gains because of interference with direct, diffuse and reflected sunlight as well as increases resulting from increased reflection. Obviously, it is impossible to estimate accurately the overall impact for Ontario, but it is expected that such effects would result in a net reduction in the heat gain rate. Another factor is the effect of snow cover on ground reflectivity, which increases the reflectivity greatly [13,20]. In the heating season in Ontario, solar heat gain factors may be about 20% higher for ground freshly covered with snow than for bare ground [13]. Again, the overall impact of snow cover on solar heat gains in Ontario is very difficult to estimate accurately. However, since the overall impacts of surrounding objects and of snow cover are opposed to each other, it was assumed that they would compensate and that the net impact could be ignored. Obviously, this point, including possible regional variations, requires further investigation.

Another factor that is ignored in equation 2.18 is the effect of heat storage. Again, this is done on the basis that heat storage effects will balance out over the heating season.

The sensitivity of the annual space heating requirements to variations in average seasonal solar heat gain rate, resulting from the uncertainties described above, has been investigated in reference [12], where it is shown that net heating-season heat losses are not very sensitive to variations in $H^*_{sol,i\ell}$ over a range of $\pm$ 25% from the nominal value.

The heating-season average solar heat gain rate was also determined by an independent method. In this method, solar heat gains on an hour-by-

hour basis throughout the heating season were determined by fundamental principles, based on the work of Stephenson [13] and Threlkeld [15], allowing for the effects of double-glazing and for heating-season average sun-hours in the Ottawa area. In this model, the residence window area was assumed to be randomly oriented in four directions (N,E,S,W). A computer program developed by one of the authors (JBF) was used in this analysis. Both methods yield essentially the same value of heating-season average solar heat gain rate.

Heating-season average wild heat gain rate, H_W^*

The heating-season average wild heat gain rate for the Ontario housing stock was established from the results of several surveys by various government and utility bodies, [4,21,22,23,24]. For the most common electrical appliances, including lighting, the average capacities, average usages and penetrations have been estimated. Similar estimates are available for non-electric household equipment. In the model, appliances and equipment have been grouped into three categories:

a) major appliances with 100% penetration (lighting, stoves, refrigerators, radios, television sets)

b) major appliances with less than 100% penetration (automatic clothes washers, clothes dryers, dishwashers, room air-conditioners)

c) minor appliances

A separate category is used for non-electric (gas) appliances.

The average annual appliance energy consumption per household has been established for the Province as a whole; no information is available on regional variations but these are not expected to be significant. Similarly, there was not sufficient information to establish reliably any seasonal variation of appliance usage. Also, no variation with house type or age was apparent.

In addition to energy generation by appliances, an allowance was made for the contribution of the inefficiency of water heating to wild heat. Although there is some dependence of this contribution on housing type, since demand for hot water varies directly with the number of persons in a

household, and the average number of persons varies with housing type (see Volume 1), this variation has been ignored in the modelling of wild heat gains, since its overall effect will be small and within the uncertainties of the data.

Finally, an allowance for the heat generated by occupants can be included in the wild heat contribution.

From a survey of the available information (see Sections 2.2 and 2.4), the heating-season average wild heat gain rate, H_W^*, was established as 3200 Btu/hr (0.94 kW) per household, which was assumed constant for all classifications i,j,ℓ and n*. This value was determined in the following manner. From Table 31, the total appliance energy requirements (including lighting) per household-year are given as 17.58×10^6 Btu/yr. From Table 23, the weighted contribution to wild heat gain from the inefficiencies of water heaters can be determined by summing the input energy requirement ($9.94 \times 10^6 + 10.73 \times 10^6 + 1.53 \times 10^6 = 22.20 \times 10^6$ Btu/yr) and subtracting from this sum the output energy requirement, 13.80×10^6 Btu/yr, which yields 8.40×10^6 Btu/yr. Therefore, the total contribution to wild heat gain from appliances, lighting and water heater inefficiencies is 25.98×10^6 Btu/yr per household. Assuming a uniform utilization of appliances, lighting and water heating throughout the year, this total is equivalent to an average rate of 2960 Btu/hr. Recognizing that utilization will be higher during the heating season and that occupants will also contribute to wild heat, this value was increased to 3200 Btu/hr for the heating season. Because of the many uncertainties in this factor, variations of $\pm$ 25%, i.e. from about 2400 Btu/hr to about 4000 Btu/hr are considered probable. For a discussion of the sensitivity of space heating demand to such variations, see reference [12].

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* The heating-season average wild heat gain rate for apartments does not include a contribution from the hot water system inefficiency, as the hot water tank is part of the central heating system, remote from individual units. The value of H_W^* used for apartments is 2700 Btu/hr (about 0.8 kW).

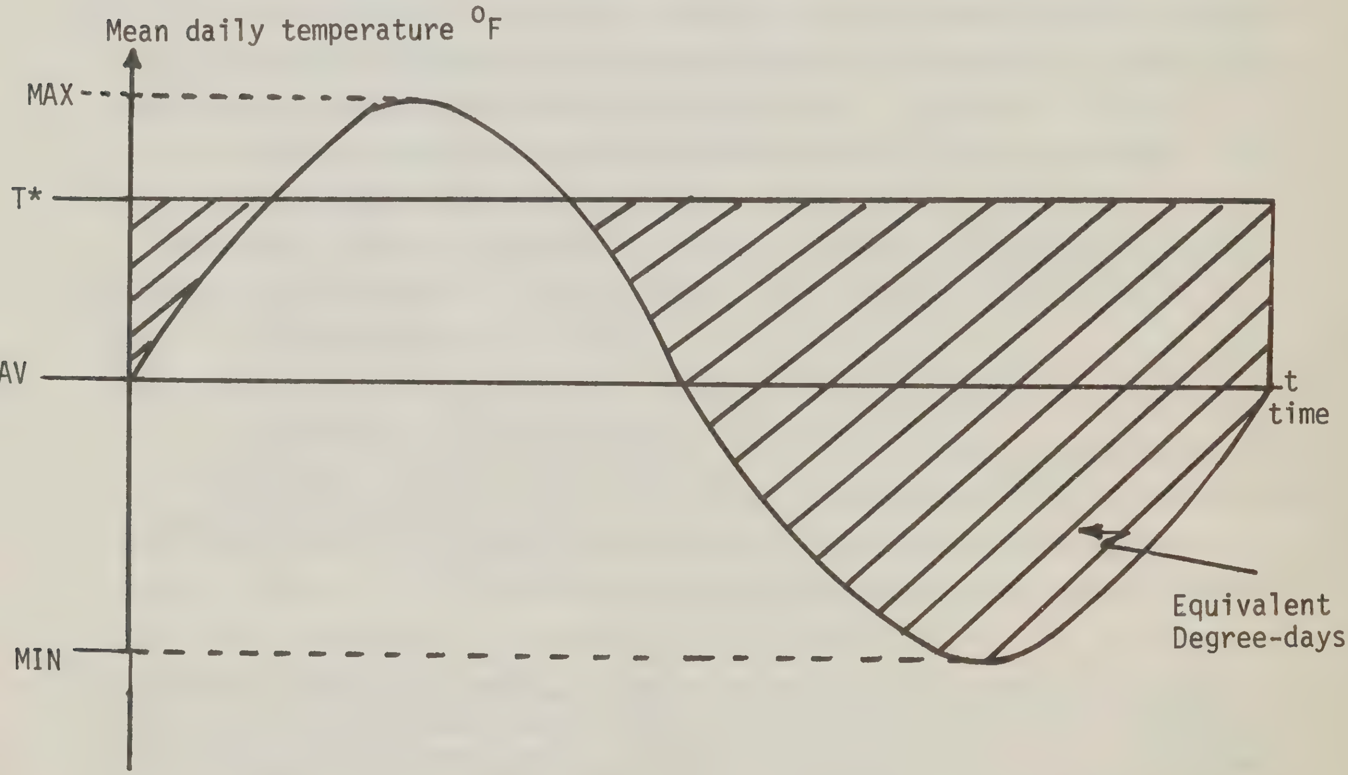
<u>Equivalent degree-days, $EDD_{ij\ell n}$</u>

The balance temperature, T*, for any classification i,j,ℓ and n can now be calculated from equation 2.9 since H^*_{sol}, H^*_W and K are now known. An effective internal temperature, T_I, of 72°F was assumed in the study, but this value is left as a variable in the program so that parameter studies may be done.*

Knowing T*, a modified value of degree-days, the equivalent degree-days, EDD, may be calculated by:

$$EDD_{ij\ell n} = \int_{season} (T^*_{ij\ell n} - T_o)dt$$

A simulation technique was developed to calculate the equivalent degree-days for any balance temperature, T*.



* The effective heating-season average internal temperature will obviously depend on many factors including thermostat location, preferences of householders, effect of night set-back if any, quality of insulation and resulting room-to-room temperature gradients, etc. It is quite likely that older houses, in particular, may have effective heating-season-average internal temperatures less than 70°F, even if thermostat settings are maintained at 72°F. This subject merits further investigation since space heating energy requirements are sensitive to variations in the effective heating-season average internal temperature.

The mean daily temperature (mean of the daily maximum and minimum) throughout the year approximates a sine curve.

To calculate the equivalent degree-days for any balance temperature, T*, the only data required are the maximum mean daily temperature (MAX) - (usually in July) and the minimum mean daily temperature (MIN) - (usually in January). Then the yearly variation of mean daily temperatures can be simulated by a sine function. The equivalent degree-days for a particular balance temperature T* can then be calculated. We see that the equivalent degree-days for the year are denoted by the shaded area in the above figure and

$$EDD_{ij\ell n}(t) = T^*_{ij\ell n} - T^o_\ell(t)$$

$$\therefore \quad EDD_{ij\ell n} = \sum_{t=1}^{365} EDD_{ij\ell n}(t) \text{ for } T^o_\ell(t) < T^*_{ij\ell n}$$

where

$$T^o_\ell(t) = YAV_\ell + \left\{\frac{MAX_\ell - MIN_\ell}{2}\right\} \sin\frac{(2\pi t)}{365}$$

and YAV_ℓ = yearly average temperature for region ℓ

MAX_ℓ = maximum mean daily temperature for region ℓ

MIN_ℓ = minimum mean daily temperature for region ℓ

To validate the procedure, the degree-days for $T^* = 65^oF$ were calculated for the regions $\ell = 1, 2, 3$ and 4 and compared to the actual recorded degree-days for this balance temperature.

It was found that for Toronto and Windsor the simulation of degree-days ($T^* = 65^oF$) approximated the weather data records [25] if the yearly average temperature (YAV) was calculated from:

$$YAV = \frac{MAX + MIN}{2}$$

However, for Ottawa and Thunder Bay the yearly average temperature was taken from climatological data [25]. The following table gives the weather data used in the simulation and compares the degree-days derived from the simulation ($T^* = 65^oF$) with those from actual weather data [25].

SIMULATED DEGREE-DAYS

	TORONTO	OTTAWA	THUNDER BAY	WINDSOR
Max: July Mean, ^{o}F	71	69	63	71
Min: Jan. Mean, ^{o}F	24	12	5	25
YAV (Yearly Av.), ^{o}F	48	42.3*	36.2*	46
YAV $(\frac{MAX + MIN}{2})$, ^{o}F	47.5*	40.5	34	48*
Degree-Days $T^* = 65^{o}F$ Simulated	6724	8574	10513	6500
Degree-Days $T^* = 65^{o}F$ Actual	6827	8693	10404	6579

* Data used in the simulation of degree-days.

Outputs from this routine include:

(1) Temperature rise due to solar radiation (See Table 7)

$$\Delta TSOL_{ij\ell n} = \frac{H^*_{sol,i\ell}}{K_{ij\ell n}} , \ ^{o}F$$

(2) Temperature rise due to wild heat (See Table 8)

$$\Delta TAPP_{ij\ell n} = \frac{H^*_{W,i}}{K_{ij\ell n}} , \ ^{o}F$$

(3) Balance temperature (See Table 9)

$$T^*_{ij\ell n} = T_I - \Delta TSOL_{ij\ell n} - \Delta TAPP_{ij\ell n} , \ ^{o}F$$

(4) The equivalent degree-days $EDD_{ij\ell n}$ (See Table 10)

2.1.5 Summary of Steps - Space Heating

The output energy requirements for space heating $OH_{ij\ell n}$ (MMBtu/dwelling yr) for dwelling type i, age j, region ℓ and fuel n are given by

$$OH_{ij\ell n} = 24\, K_{ij\ell n}\, EDD_{ij\ell n}$$

where 24 = hours in a day

$$K_{ij\ell n} = HFAB_{ij\ell n} + HINF_{ij\ell n}$$

and

$K_{ij\ell n}$ = heat loss factor by i, j, ℓ and n, Btu/hr ^{o}F

$HFAB_{ij\ell n}$ = perimeter heat loss factor by i, j, ℓ and n, Btu/hr ^{o}F

$HINF_{ij\ell n}$ = infiltration heat loss factor by i, j, ℓ and n, Btu/hr ^{o}F

and

$EDD_{ij\ell n}$ = equivalent degree-days by i, j, ℓ and n, ^{o}F day

The main steps in the calculation of EDD are:

(i) Calculate $H^*_{sol,i\ell}$, the heat gain rate due to solar radiation, Btu/hr

(ii) Calculate $H^*_{W,i}$, the wild heat gain rate, Btu/hr. (Value given)

(iii) Determine the new balance temperature, $T^*_{ij\ell n}$, from

$$T^*_{ij\ell n} = T_I - \frac{H^*_{sol,i\ell}}{K_{ij\ell n}} - \frac{H^*_{W,i}}{K_{ij\ell n}}$$

(iv) Simulate the equivalent degree-days using the calculated balance temperature, T^*.

The construction of the heat loss factor $K_{ij\ell n}$ was described in section 2.1.3 and the construction of $EDD_{ij\ell n}$ was described in section 2.1.4 of this volume.

The advantages of the Equivalent Degree-Day method are:

(1) solar gains through windows are explicitly calculated, so that investigation of possible future conservation goals via changes in construction characteristics with respect to passive solar utilization may be made.

(2) wild heat gains are explicitly calculated and their effect on output energy requirements are established.

2.1.6 Furnace Efficiency

Fossil-fuelled furnaces

The output energy requirements for space heating can be related to the annual fuel consumption of a given class of dwellings by determining the types of fuel used, the corresponding seasonal efficiencies of the furnace equipment and the heating values of the fuels.

The heating values of the various fuels used in Canadian domestic furnaces are shown in Table 12.

The seasonal efficiency of a fossil-fuelled furnace is defined for the purposes of our study as the ratio of the heat delivered to the household from the furnace for the entire heating season to the heat content of the fuel delivered to the furnace during that heating season.

The various heat losses which contribute to furnace inefficiency may be enumerated [6].

1. Heat loss as sensible heat in dry flue gases.
2. Heat loss in water vapor in the products formed by combustion.
3. Heat loss in the water vapor originating from the combustion air.
4. Heat loss from incomplete combustion.
5. Heat loss from the unburned carbon in the ash.
6. Others: radiative and convective heat losses.

Losses 1, 2 and 3 are usually referred to as stack or flue losses, 4 and 5 are burner losses and 6 encompasses distribution and system control losses.

Furnace heat loss and efficiency evaluation

There are three main factors which govern the efficiency of domestic furnaces. First, the furnace design must take into account practical, economic, technical and safety considerations: furnace combustion is a flow

process having a limited amount of time for combustion and heat exchange, as the size of the furnace is constrained by economics and other factors. Furthermore, relatively high stack temperatures are necessary to maintain natural drafts for safety considerations.

Typical measured steady-state efficiencies for new oil and gas furnaces in Canada are 74% and 76% respectively [26], and these reflect the design considerations mentioned above.

The second factor influencing the operating efficiency of the furnace is the fouling of heat exchange surfaces with extended furnace use. Because heat transfer to the heating medium deteriorates with fouling, more heat escapes up the stack and the efficiency decreases as fouling increases. It is estimated that an oil furnace may operate at 5 to 10 efficiency points lower than the design value if it is not regularly cleaned [27].

The third factor is the cyclic nature of furnace operation which is typical of residential heating applications. During transient operation, certain of the losses described above increase. Also, during start-up, a fraction of the heat released is transferred to the furnace components themselves. Although some of this heat is recovered on shut-down, a significant fraction is lost to the stack. There are also stack heat losses when the furnace is not operating.

As a result, actual operating efficiencies measured over a season will be lower than the values mentioned for new furnaces during steady-state operation.

Unfortunately, the transient nature of the furnace operation - typical of actual operation for most of the heating season, makes direct seasonal (or cyclic) efficiency measurement very difficult. Consequently, there is disagreement in the literature about the range of seasonal efficiencies characteristic of fossil fuel-fired furnaces. Table 13 shows some of the quoted ranges for gas and oil furnace seasonal efficiencies and the basis on which these estimates were made.

Choice for the model

The most useful available experimental work on this topic has been done by Ontario Hydro [28]. Based on the results of their experiments they suggested that the range of 60-70% seasonal efficiency best applies to both

oil and gas furnace operation. These results were found by comparing the fuel consumption of new fossil-fuel heated houses to the electricity consumption of new electrically-heated houses and adjusting for the various differences in house types. Although these adjustments are based on theoretical calculations of infiltration losses and heat conduction losses which are not consistent with our heat loss model, these potential errors are of second order importance as they are only used in the adjustment.

A second adjustment should be required to correct for the efficiency of electrically heated houses which was assumed in the Ontario Hydro study to be 100%. Perfect efficiency is not possible because of a limited number of thermostat controls and limited heater area which result in slight overheating of some areas, and a loss of this additional heat to the outdoors. However, it is estimated that this factor is also of second order importance. Based on these considerations, it is proposed that 65% is a representative seasonal efficiency for both* oil- and gas-furnaces that are 10 years old or less. For older furnaces it is felt that poorer designs and deterioration of equipment reduce their average seasonal efficiencies to 60%. In summary, the seasonal efficiencies used in the model are:

	Estimated Average Seasonal Efficiencies	
	Furnaces Less than 10 years old	Furnaces More than 10 years old
Oil furnace	65%	60%
Gas furnace	65%	60%

NOTES: 1. During the evaluation of model results it will be important to reassess the validity of the efficiencies with respect to the equivalent degree-day method used to predict seasonal heating requirements. Efficiency determination involves heat loss calculations which are in themselves subject to error. Thus, the proposed seasonal efficiency values must be consistent

* Although gas and oil furnace efficiencies differ when tested under laboratory conditions, these differences are considered negligible in comparison to other unknown factors (operating conditions, maintenance, etc.) that must also be considered for both furnace types.

with actual seasonal heating requirements. The term "consistency" is stressed here because there are no verification procedures known that would establish the seasonal heating requirements and actual seasonal efficiencies independently.

2. The furnace seasonal efficiencies cited above include the distribution losses which occur between the furnace and the point of use, and are assumed to be the same for both warm air and hot water systems. The heat loss for a warm air distribution system has been estimated to be about 5% of the throughput [4], and this loss is included in the seasonal efficiency, although some of this "loss" actually provides space heating. The difference between warm air and hot water systems, with respect to distribution efficiency, is not known. However, in view of the relatively small losses involved, any differences will probably be of second order.

Apartment heating systems

Apartment buildings heated with central fossil-fired furnaces have a large and diverse heat demand. Because of this, short-term cyclic variations in load are not a very significant factor contributing to losses. Also, the larger furnace is likely to be well maintained and serviced. It is estimated that such units have a seasonal efficiency of about 75%.

Effects of overcapacity on seasonal efficiency

As was discussed above, one of the factors affecting seasonal efficiency is the relatively poor performance of fossil units during standby, start-up and stopping operations. These factors become more significant when the furnace is oversized relative to the heating requirements of the house. This is because the relative amount of time which the furnace operates in the start-up or shut-down regime is increased as well as the amount of standby time, thus reducing the cyclic efficiency of the unit. This factor is an important consideration in upgrading dwelling insulation as a conservation measure. The retrofitted dwelling has a lower heat requirement relative to the furnace capacity, i.e., the furnace is now oversized. The operating efficiency drops and the heating requirements are consequently increased.

The sensitivity of seasonal efficiency to overcapacity was investigated using information derived from tests of gas [29] and oil [30] furnaces. These results were applied to a hypothetical case in which insulation is upgraded from 1966-1970 standards to 1971-1975 standards in a single detached fossil-fuel heated Ottawa house. See Table 14. It was found that an 8.2% reduction in heat loss due to better insulation could result in a 6.9 to 7.5% saving in fuel.

Although these figures are very approximate, they serve to show that actual savings due to insulation upgrading may be over-estimated by 5 to 15% if reduced seasonal furnace efficiency is not accounted for.

2.1.7 Energy Conservation Potential for Fossil-Fired Furnaces

Methods for promoting energy conservation with respect to fossil-fired furnace operation are well documented in reference [31] and are listed below.

Proper Maintenance and Servicing

The purpose of proper maintenance and servicing is to ensure a high steady-state efficiency. This involves burner adjustment, heat exchanger cleaning, etc. (See references [27] and [31] for details). The estimated potential fuel savings are 5-10%.

Hardware Improvement

Canadian [30] and U.S. [32] tests with new high-efficiency burners show a potential for fuel savings of the order of 10-20%. Modifications to the oil-furnace nozzle size and warm-air circulation fan can improve heat transfer to the warm air. These improvements cut down steady-state losses and losses due to cyclic operation. The savings obtained by individual modifications will not be additive if all modifications are made as these measures tend to reduce the same losses. The estimated collective potential saving is 10-15%.

Positive Chimney Damper

Standby and shut-down losses are increased during cyclic furnace operation due to losses up the stack. Positive chimney dampers can reduce these losses [30]. However there are safety considerations which may delay the application of this device. The estimated potential savings is 5-10%.

Heat Recovery Devices

Heat recovery devices, such as thermo-syphons, can be used to recover energy from flue gases [33]. These devices offer potential savings of about 10%. However, for safety reasons, they may not be used in Canada [31]. The potential saving is thus estimated to be nil.

Quantification in Terms of Efficiencies

These conservation measures will be manifested in terms of improved seasonal efficiencies, and these improvements have been estimated for each measure. These results are summarized in Table 15. Shown in the table are the potential step-by-step results of a thorough conservation program which would implement the above improvements in the order shown. Each succeeding modification includes the effects of the previous measures.

It is thus estimated that fossil-fired furnace seasonal efficiency could be increased from between 60-65% to about 65-70% with a minor investment and to about 75% with new burners and positive chimney dampers. See references [27], [30], and [31].

Electric Space Heating

Baseboard

Baseboard electric heaters are 100% efficient [4] at the point of use. It is not known how much loss may be attributed to inadequate control, and subsequent heat loss to the outdoors; however, this quantity is considered to be less than 5%.

Central Electric Furnaces

Losses of about 5% are usually attributed to the distribution system of central air-electric furnaces [4]. Hence, a 95% efficiency may be considered characteristic of central electric furnaces.

Heat Pumps

Ontario Hydro quotes air-source heat pump coefficient of performances of about 1.5 to 1.8 [4]. These figures are in agreement with experimental results obtained in U.S. studies [34].

2.1.8 Characteristics of Alternate Energy Sources

District Heating

The impact of district heating on Ontario urban space and water heating may be manifested in two ways. First, the relatively large size of the central boiler and the accompanying technology generally result in efficiencies of the order of 85% for the combustion and heat transfer processes. The pumping distribution requirements are about 1% to 3% of the heat load and this energy input offsets much of the energy losses due to heat transfer from the distribution system. Furthermore, the load diversity resulting from district heating, and the thermal inertia of the distribution system minimize the short term load fluctuations which are typical of individual furnaces, and thus almost eliminate start-up, shut-down and standby losses. Consequently, seasonal efficiencies of the order of 80% are possible for district heating systems. This compares to 60-65% for the individual fossil-fired units. The overall seasonal efficiencies of combined-purpose (electricity and heat) plants supplying heat to a district-heating system will also be high, with exact values being dependent on the apportionment of losses between the two end-uses. See, for example, reference [35].

The second important advantage of district heating over individual heating systems is its capability for fuel substitution. Not only is conversion possible between the conventional heating fuels (e.g., light fuel oil and gas), but larger systems can receive their heat energy from heavy oils, coal, garbage and uranium. The economies of scale of these larger central systems allow the use of environmental safeguards without excessive cost penalties.

The net effect of the introduction of district heating on residential energy demand therefore will be a reduction of the demand because of the higher conversion efficiency, and a shift towards fuels (such as coal, heavy oil, garbage and uranium) which are made accessible to the home heating market through central burning.

The penetration of district heating and the eventual fuel mix that will supply the heat energy are functions of many factors: fuel prices, fuel availability, high-density heat markets in urban areas, cost of labour

and materials relative to fuel prices, geographical matching of existing and planned heat sources with suitable heat markets, air pollution problems, availability of investment capital, government policy, etc.

An attempt to model these factors to predict future penetration of district heating into the home heating market is beyond the scope of this work. However, once the decision is made to heat a particular area in a centralized fashion, the penetration of that system is almost completely determined with time, as this is one of the prerequisites of the decision-making process. It is thus recommended that the model be adapted to allow for the penetration of heavy oil, coal, garbage and uranium for the residential space and water heating categories. This can be accomplished readily by simply adding these additional fuel categories and applying appropriate efficiencies, representing the district heating system overall efficiencies, to each category. The housing stock model and its energy demand characteristics are unchanged, of course. It would then be up to the program user to monitor the potential district heating projects in Ontario. Once actual decisions are made, the program could be updated to account for the new information.

Up to now, centralized heating in Ontario has been in the form of small group-heating systems only, generally in the high-density core regions of cities. These group-heating systems account for the small amount of heavy fuel oil used in the residential sector [36]. The extent of penetration of group-heating systems is not known and would require a separate study to determine.

Solar Energy

The economic viability of solar residential space and water heating has not yet been established in Ontario. However, we anticipate a growing fraction of space heating requirements will be provided by solar energy. Thus, the model must be designed to allow for the introduction of solar space heating.

There are two types of solar heating schemes being considered for Canadian application. One involves short-term storage (a few days) of heat energy; this system requires a supplementary heating supply. Solar energy typically provides about 50% of the heating for this type of system.

The other concept involves seasonal storage in which the solar energy provides 100% of the heating. A large portion of the heat is collected in the summer. This latter concept appears to be most suitable in group heating applications involving large-scale central storage.

The effects of solar space heating on residential energy demand can be accounted for in the model by adding categories for short-term storage solar and annual-storage solar. In short-term storage solar the fuel requirements for the supplementary system can be readily established knowing the fraction of the total load carried by the supplementary system. In annual-storage solar, there are no fuel requirements, of course.

The impact of solar energy will depend on the penetrations of these two types of system. The best indicator for modelling the penetration of solar energy at this uncertain stage is the activity of hardware suppliers for solar energy. Until a "solar industry" shows signs of large-scale development the penetration may be assumed to be insignificant. The growth potential will be directly related to industry capacity.

2.1.9 Summary of Fuel Consumption Calculations - Space Heating

Two steps are involved in calculating the fuel consumption for space heating per dwelling per year. These are:

STEP (1) Convert the output energy requirements for space heating $OH_{ij\ell n}$ to input energy requirements $IH_{ij\ell n}$ by

$$IH_{ij\ell n} = \frac{OH_{ij\ell n}}{EH_{jn}}$$

where EH_{jn} = seasonal heating efficiency by age of dwelling j and fuel type n.

Three types of fuels are considered, namely oil, gas and electricity. The efficiencies EH_{jn} used are given in the following table.

Seasonal Efficiencies for Space Heating
By Age, j, and Fuel, n. (%)

n	j	1 Pre-1966	2 1966-70	3 1971-75	4 1976 and later
1	Oil	60	65	65	65
2	Gas	60	65	65	65
3	Electricity	95	95	95	95

The input energy requirements for space heating, $IH_{ij\ell n}$, are given in Table 16.

STEP (2) Convert the input energy requirements $IH_{ij\ell n}$ to fuel consumption $FCONH_{ij\ell n}$ in natural units.

This is done by

$$FCONH_{ij\ell n} = \frac{IH_{ij\ell n}}{CONV_n}$$

where $CONV_n$ = conversion factor of the fuel type n.

The heating values of the various fuels n are given in Table 12.

The fuel consumption $FCONH_{ij\ell n}$ in gallons of oil, thousand cubic feet of gas and thousand kWh of electricity/dwelling year are given in Table 17.

2.2 WATER HEATING

2.2.1 Method

The output energy requirements for water heating, $OW_{ij\ell n}$, by structure type i, age group j, region ℓ and fuel type n are calculated from

$$OW_{ij\ell n} = W_i \, C_{p_w} (T_{max_i} - T_{min_\ell}) \, \tau$$

where:

W_i = Average quantity of hot water consumption in lb/hr per person; calculated using the data from reference [28] which are fitted by the following equation.

$$W_i = X_i (6.595 - .609X_i + .028X_i^2)$$

X_i = The average number of persons per dwelling type i. This number is obtained from reference [37] assuming that the average number of persons per dwelling for Ontario is the same for all regions. (No disaggregation is available).

C_{p_w} = Specific heat of water, 1 Btu/lb ^oF

T_{max_i} = Maximum hot water temperature as related to structure type i, ^oF

T_{min_ℓ} = Inlet water temperature to the water heater as related to the regional location ℓ, ^oF

τ = Number of operating hours per year.

HOT WATER DATA

	OTTAWA	TORONTO	WINDSOR	THUNDER BAY
Min. Hot Water Temperature	45^{o}F	45^{o}F	45^{o}F	45^{o}F
	SINGLE	SEMI	ROW	APARTMENT
Max. Hot Water Temperature	140^{o}F	140^{o}F	140^{o}F	140^{o}F
Average No. of Persons per Dwelling X_i	3.7	4	2.4	2

The subroutine HWATER calculates the output energy requirements, OW, for water heating.

The steps include (See Figure 4).

(1) Determine the average number of persons per dwelling X_i.

(2) Determine the hot water consumption W_i per dwelling type i.

(3) Calculate the output energy requirements OW_i.

The output from this program includes:

(1) Hot water consumption W_i per dwelling i (See Table 18).

(2) OW_i (See Table 19).

2.2.2 Water Heater Efficiencies

Electric Water Heaters

It is estimated that the majority of the electric water heaters on the market meet Canadian Standards Association guidelines for water heater standby losses:

110 watts for 40 gallon units

130 watts for 60 gallon units

which form the bulk of the losses for electric water heaters [38].*

The yearly standby losses implied by these standards are of the order of 1000 kWh, and this may be related to the Ontario average electric water heater energy consumption of 5400 kWh. Thus the average electric water heater efficiency is approximately 80%.

Given that a fraction of water heaters do not meet CSA standards, it is estimated that the average may be lower than 80%, which is in line with efficiencies quoted in the U.S. (i.e., 78.8%). For the study, an efficiency of 75% was used for the electric water heater stock.

Gas and Oil Water Heaters

The standby losses of gas and oil water heaters are reported to be about 40% higher [39] than the electric heater standby losses. This is due to the generally lower standard of insulation on fossil fuel water heaters - a reflection of the difference in energy costs of electricity and fossil fuels.

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* The energy lost by the water heater to the surroundings contributes in part to space heating. However, when accounting for the energy flow in the water heater, this energy is considered to be a total loss.

In addition, the fossil-fired water heaters have combustion losses, and a portion of the pilot light energy is lost to the surroundings.* These collectively have been estimated to be 20% of the input. Thus, gas and oil water heaters may be assessed to be about 45% efficient, with the gas heater being slightly more efficient than oil due to the better combustion efficiency.**

The above results are based on American gas and oil water heater standards. Unlike American practice, gas water heaters in Canada appear to have insulation similar to that for electric water heaters [40]. "Heat recovery rates" of 70% are quoted for gas water heaters, but the test procedures used to define heat recovery are not specified. Ontario Hydro have assumed the gas water heater efficiency to be 65% in a recent study [28] but no detailed analysis accompanied this figure.

Thus, there are indications that Canadian gas water heaters may be significantly more efficient than 45%, but no detailed analysis or experimental work is available to justify the use of a higher figure.

Water Heater Distribution Losses

In all cases the distribution losses of the domestic hot water system were assumed negligible. Detailed studies of hot water heater performance do not include these losses.

Apartment Water Heating

The scale of domestic water heating systems in apartment buildings benefits the efficiency of these systems in several ways: large scale hot water storage is more efficient than small scale (i.e., heat storage capacity increases proportionally with the cube of the characteristic dimension of the volume, whereas the surface area - and thus heat loss - increases only as the square of the characteristic dimension). Furthermore, the diversity of the hot water load reduces the storage needs per family unit thereby

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* The energy lost by the water heater to the surroundings contributes in part to space heating. However, when accounting for the energy flow in the water heater, this energy is considered to be a total loss.

** These differences are well within the range of accuracy assigned to these numbers so that 45% will be used for both types of heaters.

decreasing the standby losses. This also promotes more continuous operation of fossil-fired units, improving their seasonal efficiency. Thus, it is estimated that apartment fossil-fueled water heater efficiency is of the same order as the efficiency for space heating, i.e., 75%. Electric water heating efficiency for apartments would be of the order of 95%, based on the same argument as above.

2.2.3 Improvements in Water Heater Efficiency

Electric Water Heaters

The standards of the Canadian Standards Association for water heater insulation are now more demanding than those of the U.S. [38]. The main effort in this area will be to upgrade the existing electric water heater stock to meet the present standard.

Clearly, since the electric water heater losses are solely due to heat transfer, it is possible to reduce these simply by adding insulation. Ontario Hydro claims that it is practical to achieve 90% efficiency [4]. However, it is anticipated that the average efficiency of the electric water heater stock will probably not increase beyond 80%, unless the CSA adopts new standards.

Gas Water Heaters

The U.S. Department of Commerce has estimated that a 25% reduction in fuel consumption for gas water heaters is possible [41]. It is assumed that Canadian technology will follow U.S. technology, so that the gas water heating efficiency may improve from 45% to about 60%.

Oil-Fired Water Heaters

The U.S. Federal Energy Administration has estimated that similar savings could be met with oil water heaters as with the gas heaters. Thus, it will be assumed that oil water heaters show a potential for efficiency improvement from 45% to 60%.

Summary

See Table 20 for a summary of water heater efficiencies.

2.2.4 Fuel Consumption - Water Heating

In the same way as for space heating, the steps involved in the calculation of the fuel consumption, $FCONW_{ijn}$, for water heating in natural units are:

STEP (1) Calculate the input energy requirements for water heating, IW_{ijn}, from:

$$IW_{ijn} = \frac{OW_i}{EW_{jn}}$$

where EW_{jn} = water heater efficiency.

The efficiencies used are given in Table 20 and discussed in section 2.2.3. The present-level values are used for age groups j = 1, 2 and 3 and the estimated potential values are used for the post-1975 period. For oil and gas water heaters the efficiencies are the same.

The input energy requirements for water heating, IW_{ijn}, are given in Table 21.

STEP (2) Calculate the fuel consumption $FCONW_{ijn}$ for water heating in natural units from

$$FCONW = \frac{IW_{ijn}}{CONV_n}$$

where $CONV_n$ are the conversion factors giving the heating value of the various fuels n (Table 12).

The fuel consumption $FCONW_{ijn}$ for water heating in natural units is given in Table 22.

A sample calculation for the average water heating input energy requirements for Ontario is given in Table 23. This calculation was made by weighting the output requirements per household for electric, gas and oil water heaters by their saturation level and then dividing by the efficiency of each fuel type.

2.3 SPACE COOLING

2.3.1 Method

The output energy requirement for a centrally-cooled dwelling by structure type i, age group j, region ℓ and fuel type n, $OHA_{ij\ell n}$, is calculated from:

$$OHA_{ij\ell n} = 24\ C\ (FCL_{ij\ell n} + SRL_{i\ell} + ICL_{ij\ell n})\ ACD_{\ell}$$

where

- 24 = hours in a day
- C = constant to allow for latent heat gain from occupants, appliances, etc.
- FCL = perimeter cooling load by i, j, ℓ and n, Btu/hr
- SRL = cooling load for the windows by i, and ℓ, Btu/hr
- ICL = infiltration cooling load by i, j, ℓ and n, Btu/hr
- ACD = number of operating space-cooling days by ℓ.

The program AIRCON calculates $OHA_{ij\ell n}$. The steps involved are as follows. (Figure 5).

STEP (1) Determine the perimeter cooling load $FCL_{ij\ell n}$ from

$$FCL_{ij\ell n} = \sum_{k=1}^{8} DETD_{\ell}^{k}\ U_{j\ell n}^{k}\ A_{i}^{k}$$

where

- DETD = Design equivalent temperature difference, ^{o}F
- U^k = Overall heat transfer coefficients for the different construction components k, by j, ℓ and n, Btu/hr ft^2 ^{o}F. These are the same as calculated in section 2.1.3 of this volume.
- A^k = Areas of the different construction components, k, by type of dwelling i, ft^2. (See Table 1).

NOTE: Values of DETD for different types of construction components (i.e. walls, floors, ceilings, etc.) are expressed as functions of the outdoor summer design temperature in the ASHRAE Handbook of Fundamentals [6]. These values include the effects of solar gains through the different construction components and of heat storage in the building materials. Linear equations for DETD in terms of the outdoor summer design temperature, T_{o,av_ℓ}, were derived from the data of reference [6] and are given in Table 4c. The values of T_{o,av_ℓ} for the four regions of the model are given in Table 4a. Values given in Table 4a are the temperatures which are exceeded 2½% of the time during July.

STEP (2) Determine the cooling load for windows, SRL_ℓ, from

$$SRL_{i\ell} = q_\ell^W * WA_i$$

where q_ℓ^W = total heat gain rate through double pane ordinary glass, Btu/hr ft^2 of window area.

WA_i = window area (ft^2) for dwelling type i (See Table 1).

Values of the total heat gain rate through the windows (window factors) are based on data from reference [6]. These values allow for both solar heat gains and convection and conduction heat transfer. Average values for randomly-oriented windows for the cooling season for the four regions of the model were established from data in reference [6], and are represented by:

$$q_\ell^W = -1.75 + 0.2\,(T_{o,av_\ell})\ \text{Btu/hr ft}^2$$

Values of T_{o,av_ℓ} are given in Table 4a.

STEP (3) Determine the infiltration cooling load ICL, Btu/hr, by i, j, ℓ and n from

$$ICL_{ij\ell n} = \eta_{jn}\,\rho_a\,C_p(T_{o,av_\ell} - T_{SI})\,V_i$$

where η_{jn} = number of air changes per hour by age j and fuel n.

ρ_a = house air density, 0.075 lbm/ft^3.

C_p = specific heat of air, 0.24 Btu/hr ^oF

T_{o,av_ℓ} = summer design temperature, ^oF, by region ℓ (See Table 4a).

T_{SI} = summer inside design temperature, ^oF.

V_i = volume of building by type i, ft^3. This is calculated from

$$V_i = ALIV_i \ (Z1)$$

where

$ALIV_i$ = livable area of dwelling type i (Table 1)

and $Z1$ = average height of the ceiling = 7'6" (effective height considering closet space, walls, furniture, etc.)

Although summer infiltration rates are generally lower than those in the winter [6], the values used in the model are the same as those for the winter, but are equal to those recommended by ASHRAE [6].

STEP (4) Determine the output energy requirements for space cooling, OHA, from

$$OHA_{ij\ell n} = 24 \ C \ [FCL_{ij\ell n} + SRL_{i\ell} + ICL_{ij\ell n}] \ ACD$$

where

ACD = average number of operating space-cooling days, days/yr.

C = constant = 1.3 to allow for latent heat gain from occupants, appliances, etc. (Suggested value from reference [6]).

A mean value of ACD of 20 days is used in the study. This value, with the summer design temperatures, T_{o,av_ℓ}, window factors, q_ℓ^W, and summer

infiltration rates gives average space-cooling loads consistent with present Ontario Hydro data.

The method used for the calculation of space-cooling loads is a simplified one which represents present demands well, but which may somewhat over-predict demands as the space-cooling load in Ontario grows. Therefore, as space-cooling becomes more important, this model should be re-assessed and modified as necessary to ensure reliable forecasts.

The outputs from this program are:

(1) Power required for space cooling, $ROHA_{ij\ell n}$, Btu/hr, where

$$ROHA_{ij\ell n} = 1.3\ (FCL_{ij\ell n} + SRL_{i\ell} + ICL_{ij\ell n})$$

(See Table 24).

(2) Total output energy requirements for space-cooling, $OHA_{ij\ell n}$, MMBtu/dwelling yr. (See Table 25).

2.3.2 <u>Energy Conversion Characteristics of Central Space-Cooling Systems</u>

There are two factors that are used to measure the effectiveness of cooling equipment: the coefficient of performance (COP) and the electrical efficiency ratio (EER). The two differ only in the units used to express them. The electrical efficiency ratio for air conditioning units is defined as the cooling energy output capacity in Btu/hr divided by the input electrical capacity of the unit in watts while the COP is a dimensionless ratio of the cooling rate to the energy input rate.

Although a wide range of EER's are possible for central air conditioners, the most probable range is from 8 to 10, with the most common types having an EER of about 8. This compares to typical window air conditioner EER's of about 6.5 to 7 [42]. A survey by the U.S. Federal Energy Administration showed that EER's of up to 12 were possible for the 115 volt window models [43]. This suggests that there is room for efficiency improvement with the central units, probably at the expense of size and cost.

Table 26 is based on the limited information available on the subject of electrical efficiency ratio for central air conditioners. For the

purposes of initial model formulation, the lower values of these ranges were used. This was done because the EER is a steady-state rating and does not account for transient operation losses.

The sources of uncertainty in these estimates are: 1) the limited information on the range of central air conditioner EER's that are characteristic of the Ontario market, and, 2) the relationship between steady state and seasonal coefficients of performance (i.e., rating vs. actual performance).

Should central space cooling become widespread in Ontario, (presently less than 5% penetration in the residential sector [4]) a more reliable coefficient of performance could be obtained by establishing the penetrations of the various units that are available on the market in order to weight the ratings. Experimental verification of actual performance is also recommended in order to determine the effects of cyclic operation on the COP.

2.3.3 Fuel Consumption - Space Cooling

The fuel consumption for space cooling is calculated in two steps:

(1) The input energy requirements, $IHA_{ij\ell n}$, for space cooling is calculated from

$$IHA_{ij\ell n} = \frac{OHA_{ij\ell n}}{COP}$$

where COP = coefficient of performance.

A value of COP = 2.34 was used for all current housing stock and a value of 2.64 for future new housing stock. The choice of these values was explained in the previous section.

The input energy requirements, $IHA_{ij\ell n}$, are given in Table 27.

(2) The fuel consumption, $FCONHA_{ij\ell n}$, is calculated from

$$FCONHA_{ij\ell n} = \frac{IHA_{ij\ell n}}{CONV_3}$$

where $CONV_3$ = the conversion factor for electricity.

Table 28 gives the values of $FCONHA_{ij\ell n}$.

2.4 RESIDENTIAL APPLIANCE ENERGY UTILIZATION

The principle involved in estimating the energy requirements of appliances in Ontario homes is the same as for the other end-use categories in the model:

$$\text{Demand} = \frac{\text{device output} \times \text{utilization factor} \times \text{penetration}}{\text{conversion efficiency}}$$

However, the approach to the determination of energy demand for appliances is different to the approach used for space heating because appliances are in most cases considered to be the end use, thus making it difficult to define "device output" and "conversion efficiency" (e.g. it is not considered practical to equate clean clothes to an energy output of clothes washers). Consequently, the terms "device output" and "conversion efficiency" are grouped to form the "device capacity" for the purposes of establishing appliance energy demand in the base period.*

2.4.1 Base Period Calculation

The average capacities of the most common electrical appliances available on the Ontario market have been estimated by Ontario Hydro [24]. There are about 60 such appliances listed. Along with these capacities are estimates of monthly electrical energy usage that are associated with each appliance. Typical utilization factors may be deduced from the capacities and electrical demand for each appliance.

This information is available for Ontario as a whole, and variations of these numbers by region or house type are not considered to be significant either from the accounting or predicting point of view. The appliances available to Ontarians are much the same across the province, and the average utilization is not considered to be a strong regional variant.

The saturations or penetrations of some of the major electrical appliances are available by region from reference [21]. Other sources for the saturations of appliances for Ontario include references [22] and [23].

---

* Note that device "efficiencies" will be estimated, or assigned a value, to be consistent with the model format, and to allow the modelling of improved device performance with time.

Some provincial appliance saturation trends are also available from Ontario Hydro [4].

From the available figures the energy consumptions of the major electrical appliances used in Ontario were calculated. The results are shown in Table 29.

2.4.2 Model Considerations

Although it would be theoretically possible to account for the yearly energy consumption of each electrical applicance type available on the market, information on the saturation of the many smaller appliances is not readily available. Furthermore, an individual model for each major appliance is not warranted because the individual demands represent small fractions of the total. Figure 6 shows the individual major electrical appliance energy consumptions over the last 20 years. It may be observed that demand of individual appliances is much less "predictable" than the demand of all the appliances combined.

For modelling purposes therefore, the appliance energy demand will be accounted for by grouping the appliances into certain categories.

Combining appliances into groups will simplify the modelling task, and at the same time will represent behavioral characteristics that may be typical of appliance groups but not necessarily of individual units.

Two appliance groups were chosen to represent the major appliances: those appliances having 100% saturation, and those appliances having less than 100% saturation. Small appliances form a third group, "other".* The appliance groups having 100% saturation are: lighting, cooking equipment, refrigerating equipment and audio-visual equipment (i.e. radio - TV etc.). That is, all households have some appliances falling in each one of these groups. Thus, the variations in energy demand will only be a result of utilization and efficiency changes. The penetration will be fixed. The second group is composed of: clothes washers, clothes dryers, dishwashers and room air conditioners - all major appliances with varying degrees of penetration. Here, penetration will have to be modelled as well as technology change and utilization characteristics.

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* The model also includes a fourth group which permits the handling of appliances which may use gas, e.g. stoves and clothes dryers.

Tables 30 and 31 show the saturation and resulting energy demands for the base period, according to the established classification. (The figures in Table 31 shown for gas appliances are a result of the analysis described in the next section.)

2.4.3 Appliance Efficiency Factor

The electrical appliance energy demand for Ontario has been established in the previous section using appliance saturations and average yearly consumption figures. However, in order to model the effects of technical improvement and fuel substitution, it is desirable to establish the appliance energy output which can be divided by an efficiency term to obtain appliance energy demand. It will be noted that many energy conservation measures are described in terms of percent fuel saving, and thus, do not require an efficiency definition. However, other conservation measures are described in terms of efficiency improvement. Thus for the sake of model consistency the "efficiency-energy output" approach will be used.

As mentioned above, "efficiency" has not been determined for most of the appliances, as their energy output has little significance. For these units, an "efficiency factor" of 100% will be assigned for the base year. Technical improvements in subsequent years would result in efficiency factors of greater than 100%. It is emphasized that the concept "efficiency factor" is used for accounting purposes only, and the numbers per se will have no significance.

Electrical and gas ranges and clothes dryers do have defined efficiencies since the function of both types of appliances is to deliver heat energy. Electric ranges are estimated to have efficiencies of the order of 45%, based on information provided by Ontario Hydro [4]. There are other components in the cooking category,* but the range accounts for a large percent of the energy use in this group. Electric clothes dryers are estimated to have efficiencies of the order of 40% [4].

These efficiency factors are listed in Table 32 for the appliance groupings specified previously.

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* The cooking category includes all associated "plug-in" cooking appliances, e.g. electric frying pans, kettles, etc. [4].

Using the energy demand of appliances listed in Table 31 energy outputs may be obtained using the efficiency factors, as shown in Table 33. Again, these energy output figures only have as much significance as the efficiency factors used to obtain them.

Gas Appliances

The performance characteristics of gas ranges and gas clothes dryers are not readily available in literature. However, these can be estimated using information on expected range and dryer gas consumption improvements projected for 1980 by the U.S. Department of Commerce [41], [43]. It is assumed that the suggested potential improvements for the gas appliances will result in gas appliance efficiencies which will be similar to those of the next generation of electric stoves and dryers.

2.4.4 Technological Change - Appliances

The Canadian Federal Government has recently (1975) initiated a program of energy conservation which encompasses all end-use sectors of the Canadian economy. That part of the program which concerns appliance energy use is presently being organized by the Consumer Research Branch of the Department of Consumer and Corporate Affairs, and the Office of Energy Conservation of the Department of Energy, Mines and Resources. The first phase of the conservation program will involve the mandatory labelling of appliances with energy consumption figures and operating costs in such a way that it can be seen by the purchaser before the decision is made to purchase. [44], [45]. The future course of action has not been determined yet.

Ideally, a model of the effects of this program would have to account for appliance manufacturers' responses, and consumer response to the program.

The method used consists of establishing appliance performance characteristics for the base period and their potentials for performance improvements given present available technology. These potentials define the limits to the manufacturers' responses to government programs. The effects of the new appliance performances on energy demand are functions of appliance turn-over rates and penetrations, which can be handled through economic analysis.

The advantage of the proposed approach is that it defines a limit to the potential for energy conservation, and models the future change in demand according to that limit. The accuracy of the projection is largely controlled by the accuracy of the estimated potential for improvement in appliance energy utilization, which can be based on scientific research.

Unfortunately, the proposed federal labelling program does not include an assessment of the potential improvement in Canadian appliance energy consumption, so that information from a similar program in the United States is required for a "trial-run" of the model. The available information is in the form of estimated potential energy savings for each of the major appliances as estimated by the U.S. Department of Commerce and the Federal Energy Administration. These estimates are shown in Table 34. They apply to appliances that will be manufactured after 1980, and would result in an overall appliance energy demand reduction of 20% (See reference [43] for detailed analysis of each appliance).

As an example of the use of such figures, it will be assumed that the Department of Commerce estimates are applicable to the Canadian industry. We have chosen to represent these fuel savings in terms of an improvement in efficiency factor defined previously. The resulting changes in efficiency factors which would be compatible with the model formulation are shown in Table 35. If the new appliances replaced all of the present ones a 20% reduction in appliance energy demand would result.

2.4.5 Discussion of Data Base

The saturations and annual energy demands used for the base-year appliance energy demand calculations come from well-documented sources. Information is not available on the income or regional distribution of appliance energy demands. However, any resulting errors are considered acceptable, given that a survey of such distributions is not considered practical and would not alter the accuracy of the aggregated result significantly.

The efficiency factors are introduced only to permit the representation of technological change and fuel substitution. The U.S. Federal Energy Administration will attempt to establish the true efficiencies of

major appliances in the near future, as part of the U.S. energy conservation program. The Canadian Federal Department of Consumer and Corporate Affairs (Consumer Research Branch) which is in charge of evaluating and recommending energy conservation measures for the appliances, has indicated that much of the U.S. work in this field will be applied to Canada, as the size of our appliance market does not allow for an extensive research program. Thus, the monitoring of U.S. activity in this field will be an important step in upgrading the quality of data where appliance efficiencies are concerned.

The present scheme for accounting for the appliance energy demand by groups is considered to be an efficient way of modelling this particular end-use sector. The groupings will eliminate the need for a multitude of models which would be difficult to formulate separately. Furthermore, it is believed that the collective appliance energy demand is dependent on fewer parameters than the demand of individual appliance types.

However, this approach does not limit the flexibility of the model. The base data used to formulate the present model is also presented to allow the model user to investigate individual appliances or other groups according to user needs.

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PROGRAM TO CALCULATE OUTPUT ENERGY
REQUIREMENTS OF FIXED EQUIPMENT
- ONTARIO RESIDENTIAL SECTOR

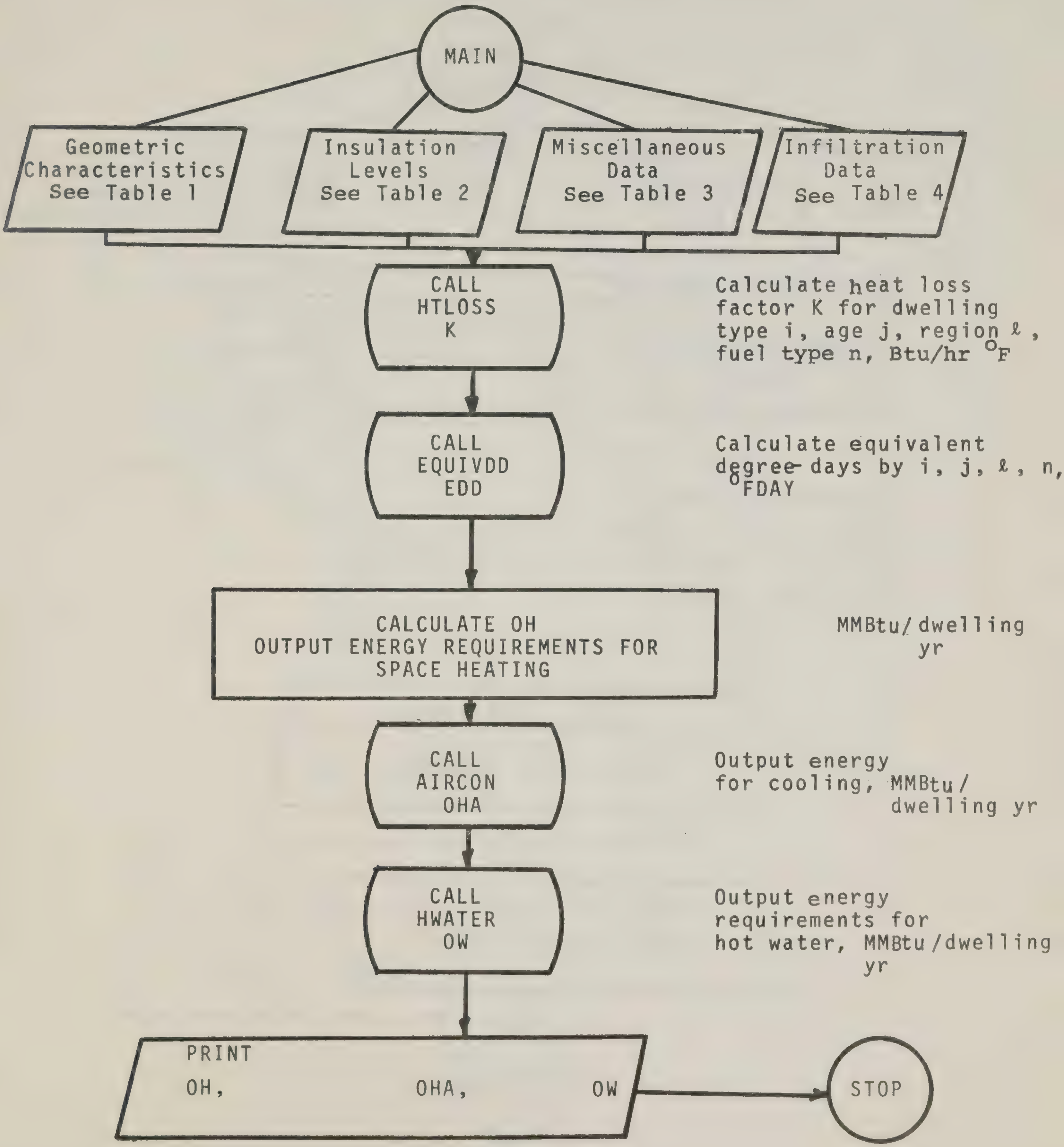


Fig. 2

SUBROUTINE HTLOSS - To Calculate The Heat Loss Factor, $K_{ij\ell n}$

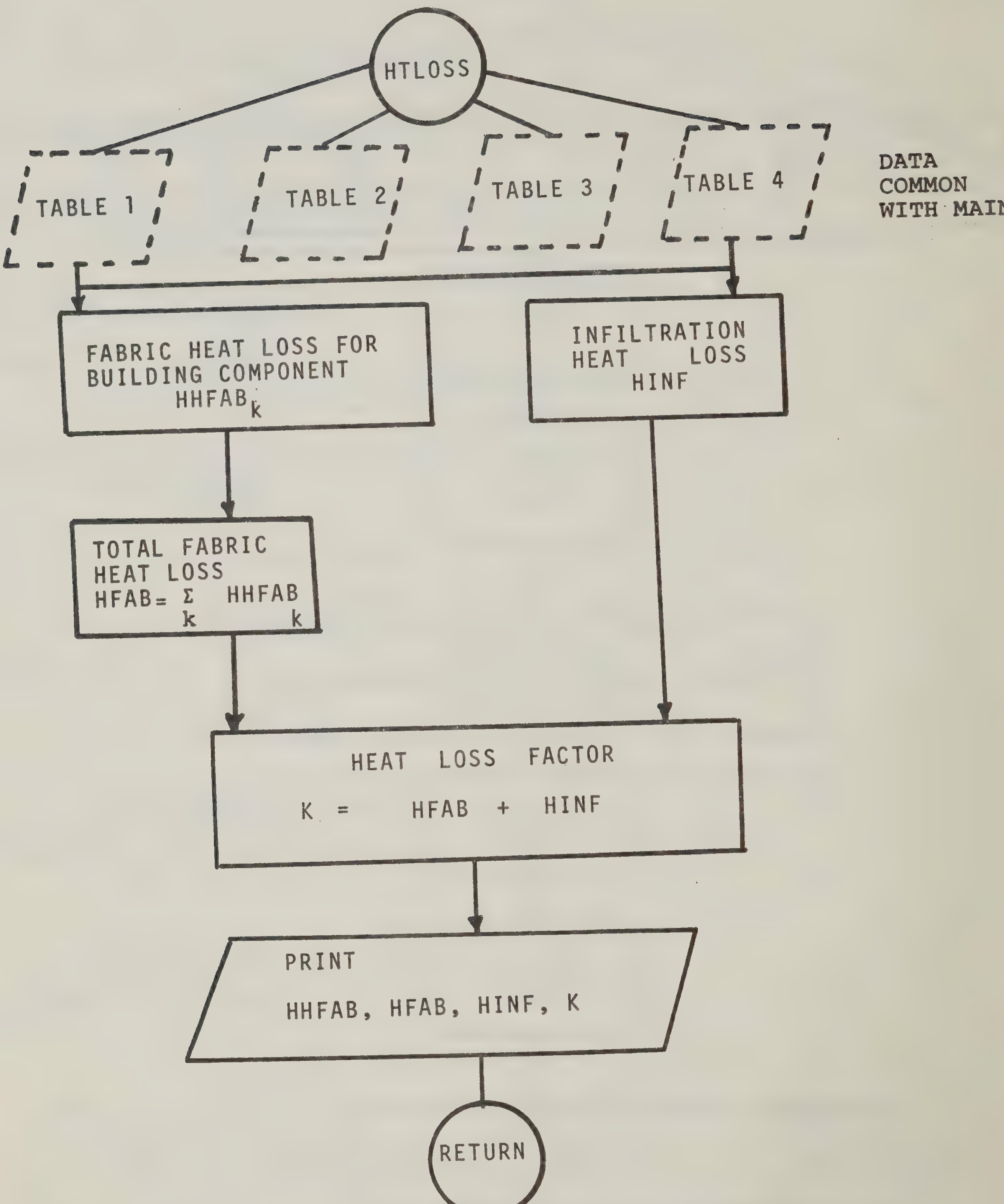


Fig. 3

SUBROUTINE EQUIVDD: To Calculate the Equivalent Degree-Days, $EDD_{ij\ell n}$

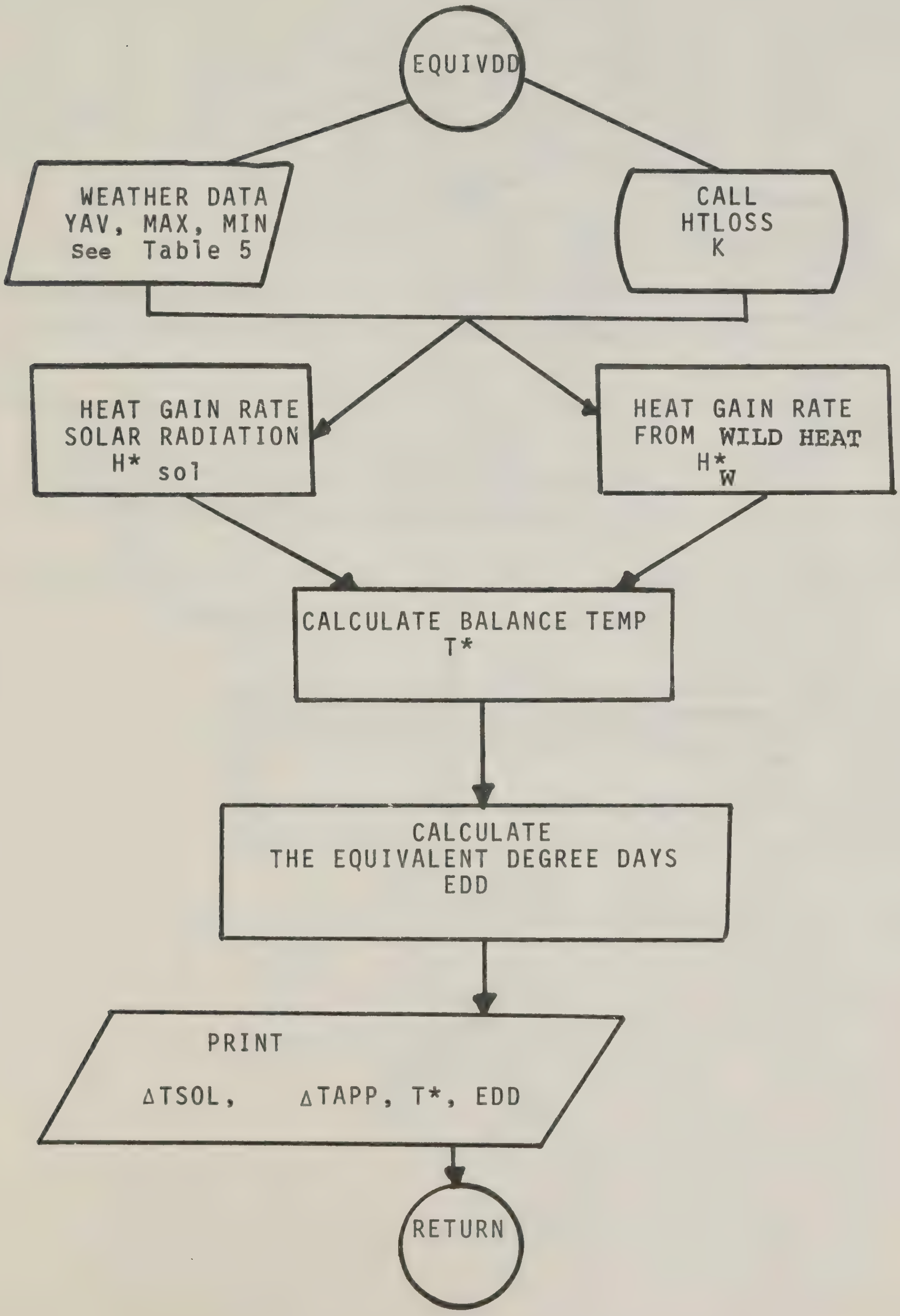


Fig. 4

SUBROUTINE HWATER - To Calculate the Output Energy Required for Water Heating, OW_i

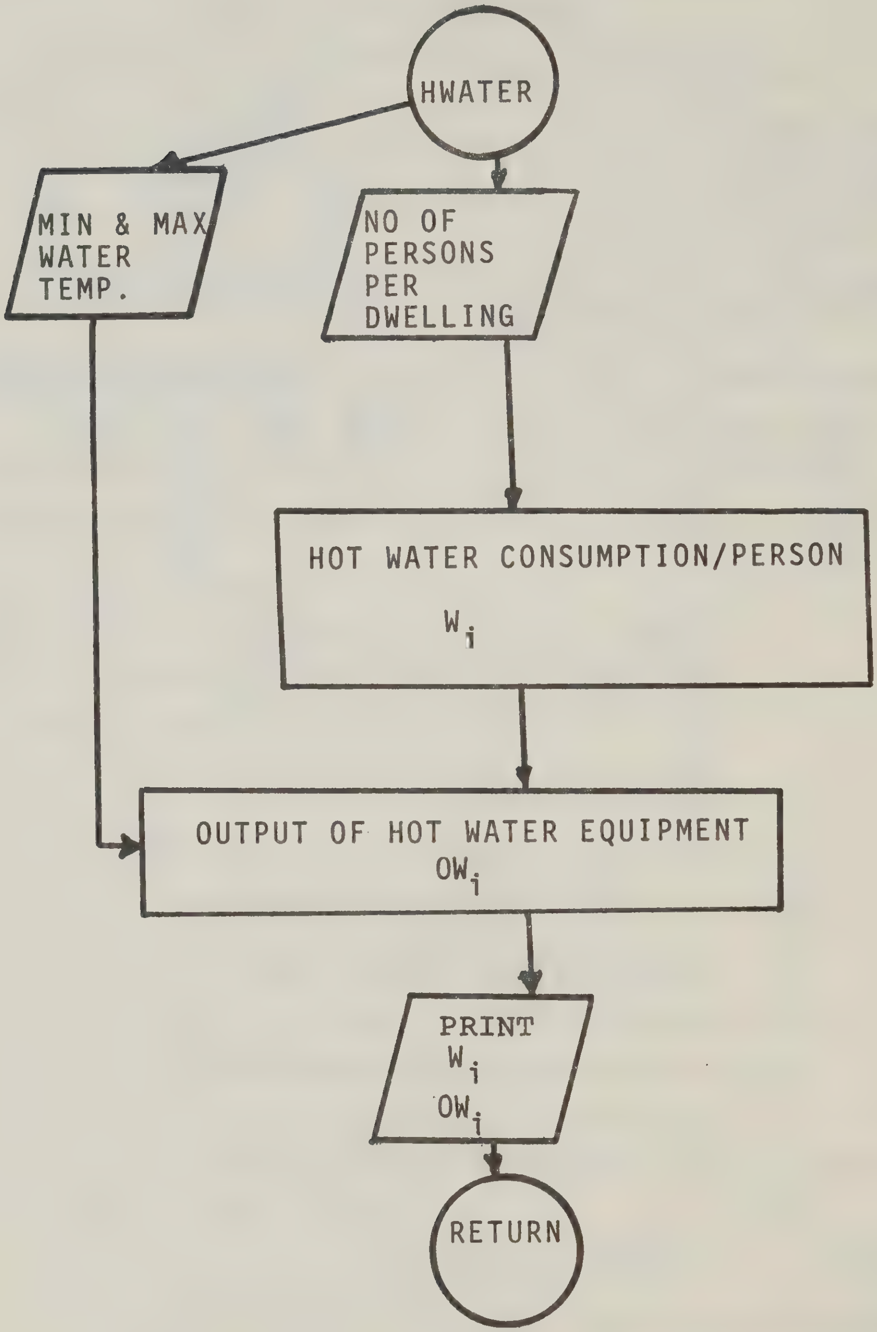
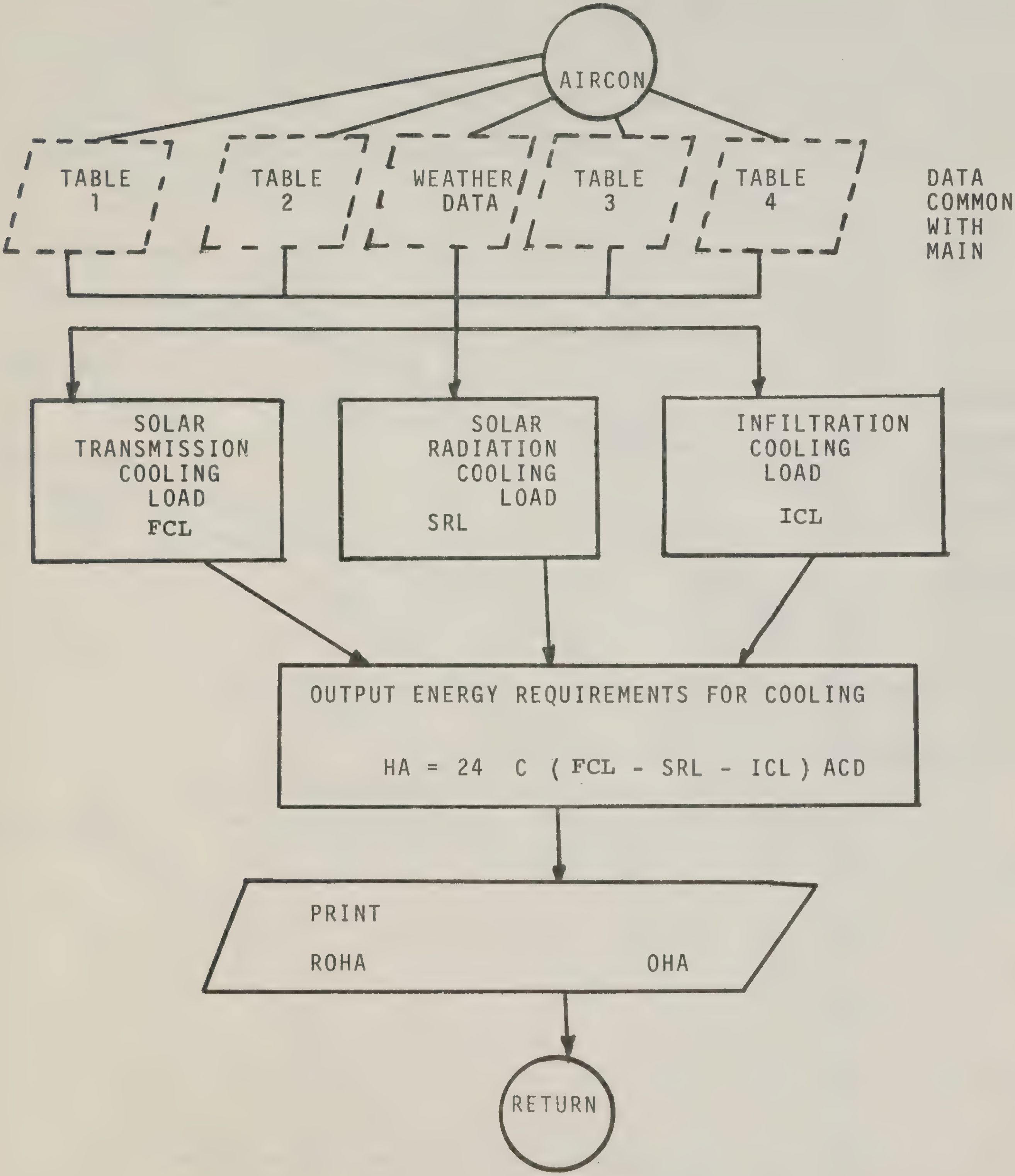


Fig. 5

SUBROUTINE AIRCON - To Calculate the Output Energy Requirements for Centrally-Cooled Dwellings, $OHA_{ij\ell n}$



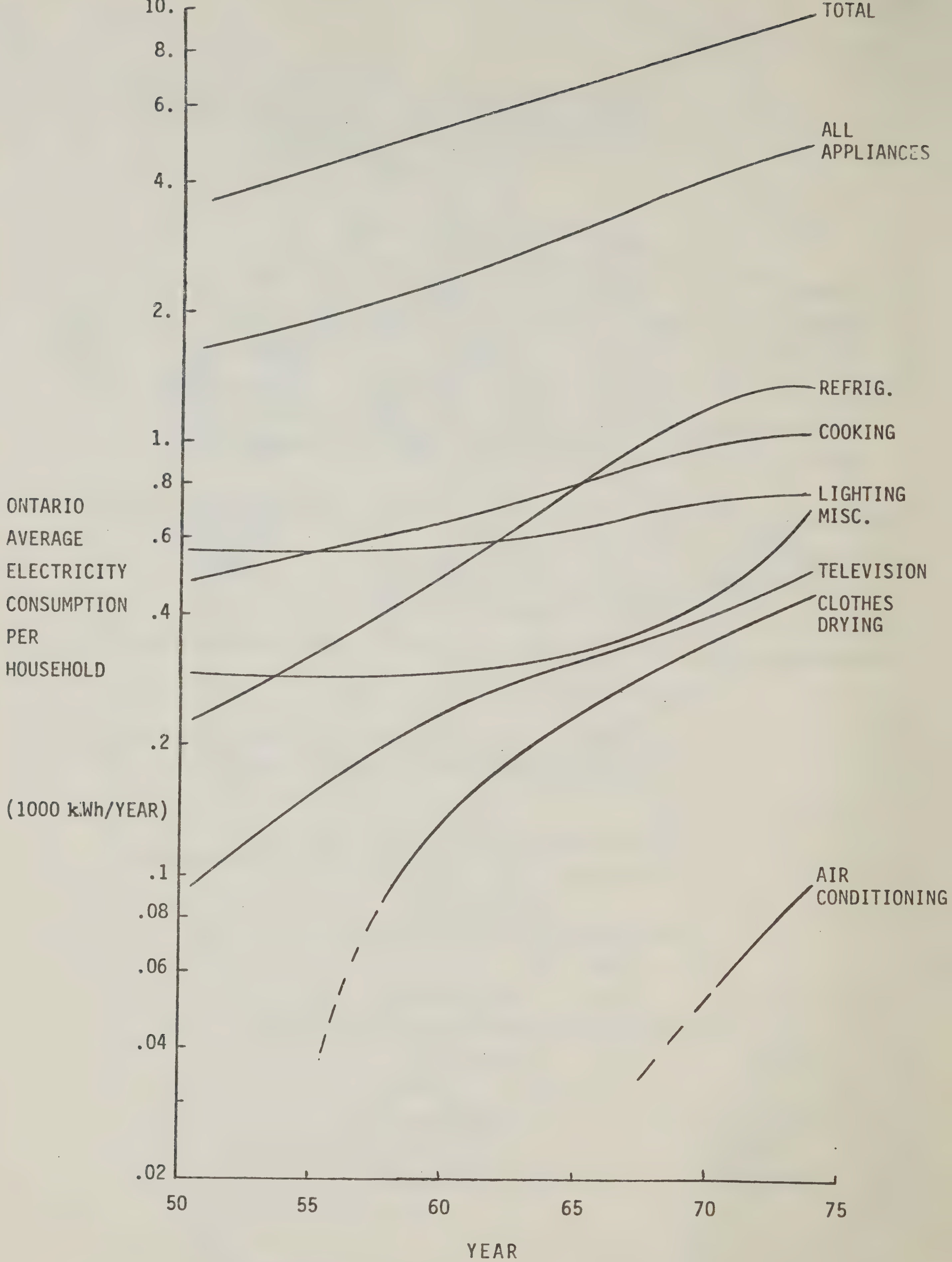


Fig. 6 TRENDS IN THE YEARLY ENERGY CONSUMPTION ATTRIBUTED TO MAJOR APPLIANCES

TABLE 1

AREAS OF DIFFERENT CONSTRUCTION COMPONENTS
FOR DWELLINGS*

DESCRIPTION OF COMPONENT	UNITS	DWELLING TYPE i			
		SINGLE DETACHED 1	SEMI-DETACHED & DUPLEX 2	ROW HOUSE 3	APARTMENT 4
LIVABLE FLOOR AREA	FT^2	1334	1203	1080	740
k - Construction component					
1 CEILING	FT^2	1139	800	560	385
2 EXTERIOR WALL	FT^2	1265	912	596	330
3 & 4 FOUNDATION WALL	FT^2	1249	759	353	80
5 WINDOWS	FT^2	214	144	109	41
6 DOORS	FT^2	39	39	39	39
7 FLOORS	FT^2	0.0	0.0	0.0	0.0 **
8 BASEMENT SLAB	FT^2	900	757	456	160

* 1969 CMHC Housebuilders survey[2].This survey covers a representative sample of housing stock built in 1969. It does not restrict itself to NHA housing.

** For the present analysis floors above a crawl space were not considered. However, the structure of the program permits their inclusion if required.

TABLE 2a

INSULATION LEVELS FOR NON-ELECTRICALLY-HEATED DWELLINGS ($n=1$) FOR ALL TYPES, $i = 1-4$, BY AGE, j, REGION, ℓ, AND BUILDING COMPONENT. (THERMAL RESISTANCE, $(Btu/hr\ ft^2\ ^oF)^{-1}$)

REGION ℓ	AGE	BUILDING COMPONENT			
		CEILING	EXTERIOR WALL	BASEMENT WALL	FLOORS
1 Ottawa (EASTERN)	Pre-1966	7	7	0	7
	1966-1970	10	7	7	10
	1971-1975	12	10	7	10
	Post-1975	20	12	10	12
2 Toronto (CENTRAL)	Pre-1966	7	7	0	7
	1966-1970	7	7	0	7
	1971-1975	10	7	7	7
	Post-1975	12	10	8	10
3 Windsor (SOUTH WESTERN)	Pre-1966	7	7	0	7
	1966-1970	7	7	0	7
	1971-1975	10	7	7	7
	Post-1975	12	10	8	10
4 Thunder Bay (NORTHERN)	Pre 1966	7	7	0	7
	1966-1970	10	7	7	10
	1971-1975	12	10	10	10
	Post-1975	20	12	10	12

TABLE 2b

INSULATION LEVELS FOR ELECTRICALLY-HEATED DWELLINGS (n=2) FOR ALL TYPES, i = 1-4, BY AGE, j, REGION, ℓ, AND BUILDING COMPONENT. (THERMAL RESISTANCE, $(Btu/hr\ ft^2\ {}^oF)^{-1}$)

			BUILDING COMPONENT			
REGION ℓ	j	AGE	CEILING	EXTERIOR WALL	BASEMENT WALL	FLOORS
1 Ottawa (EASTERN)	1	Pre 1966	20	10	7	7
	2	1966-1970	20	10	7	10
	3	1971-1975	20	12	8	10
	4	Post-1975	30	12	10	12
2 Toronto (CENTRAL)	1	Pre 1966	12	8	7	7
	2	1966-1970	12	8	7	7
	3	1971-1975	20	12	8	10
	4	Post-1975	20	12	10	12
3 Windsor (SOUTH WESTERN)	1	Pre 1966	12	8	7	7
	2	1966-1970	12	8	7	7
	3	1971-1975	20	12	8	10
	4	Post-1975	20	12	10	12
4 Thunder Bay (NORTHERN)	1	Pre 1966	20	10	7	7
	2	1966-1970	20	10	7	10
	3	1971-1975	20	12	8	10
	4	Post-1975	30	12	10	12

TABLE 3a

OTHER GEOMETRIC CHARACTERISTICS
OF DWELLINGS

Description of Component	Unit	Uniform over i,j,ℓ and n
Basement width	FT	30.0
Basement length	FT	30.0
Ceiling height	FT	7.5
Basement height	FT	7.0
Foundation wall depth below grade (total)	FT	6.0
Foundation wall depth below grade (insulation)	FT	4.0
Thickness basement gravel base	IN	5
Thickness concrete slab	IN	3.5
Width of basement slab insulation	FT	0.0

TABLE 3b

OVERALL HEAT TRANSFER COEFFICIENTS FOR OTHER COMPONENTS OF DWELLINGS

Basement Wall below Grade

		Depth below Grade, ft						
		1	2	3	4	5	6	7
Foundation Wall *	Btu/hr ft^2 ^oF	0.41	0.222	0.155	0.119	0.096	0.079	0.069

Basement Floor

	Depth below Grade, ft.	U, Btu/hr ft^2 ^oF			
Basement Floor Air to Air Heat Transfer Coeff.*	5	0.032	0.029	0.026	0.023
	6	0.030	0.027	0.025	0.022
	7	0.029	0.026	0.023	0.021
	Width of basement floor, ft.	20	24	28	32

	U, Btu/hr ft^2 ^oF
WINDOW*	0.55
DOOR*	0.43

*Source: Reference [7].

TABLE 4

DESIGN TEMPERATURE AND INFILTRATION DATA

Table 4a Summer Design Temperatures by Region, ℓ, T_{o,av_ℓ}
Average Daily Maximum Temperatures Exceeded
2½% of the time in July

	UNIT	OTTAWA 1	TORONTO 2	WINDSOR 3	THUNDER BAY 4
Summer Design Temp	^oF	87	87	90	83

Source: Reference [6]

Table 4b Number of Air Changes per Hour by Age, j, and Fuel Type, n

Age, j / Fuel, n	1 Pre-1966	2 1966-1970	3 1971-1975	4 Post - 1975
Non-Electric n = 1	0.5	0.5	0.5	0.5
Electric n = 2	0.3	0.3	0.3	0.3

TABLE 4c

DESIGN EQUIVALENT TEMPERATURE DIFFERENCES (DETD) FOR SPACE COOLING ANALYSIS, ^oF

Component, k		Empirical Equation
1	Ceiling	$DETD_\ell^1 = -51.0 + T_{o,av_\ell}$
2	Exterior Wall	$DETD_\ell^2 = -71.4 + T_{o,av_\ell}$
3	Foundation Wall above Grade	$DETD_\ell^3 = -78.7 + T_{o,av_\ell}$
4	Foundation Wall below Grade	$DETD_\ell^4 = 0$
5	Windows	See page 46
6	Doors	$DETD_\ell^6 = -71.4 + T_{o,av_\ell}$
7	Floors	$DETD_\ell^7 = -80.0 + T_{o,av_\ell}$
8	Basement Slab	$DETD_\ell^8 = 0$

T_{o,av_ℓ} - outdoor summer design temperature for region ℓ. See Table 4a.

TABLE 5

WEATHER DATA FOR EQUIVALENT DEGREE-DAY CALCULATION:

	REGION			
	OTTAWA 1	TORONTO 2	WINDSOR 3	THUNDER BAY 4
Maximum Mean Yearly Temp. ^{o}F	$69^{o}F$	$71^{o}F$	$71^{o}F$	$63^{o}F$
Minimum Mean Yearly Temp. ^{o}F	$12^{o}F$	$24^{o}F$	$25^{o}F$	$12^{o}F$
Yearly Average Temp ^{o}F	$42.3^{o}F$	$48^{o}F$	$48^{o}F$	$36.2^{o}F$

Source: Reference [25]

HEATLOSS FACTORS, $K_{ij\ell n}$, Btu/hr ^oF

TABLE 6

NON-ELECTRICALLY HEATED, n=1

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	800 800 800 800	620 800 800 620	585 620 620 585	535 580 580 535
2 SEMI & DUPLEX	560 560 560 560	447 560 560 447	423 447 447 423	389 419 419 389
3 ROW	371 371 371 371	313 371 371 313	297 313 313 297	275 295 295 275
4 APARTMENT	193 193 193 193	173 193 193 173	163 173 173 163	150 162 162 150

ELECTRICALLY HEATED, n=2

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	522 562 562 522	522 562 562 522	507 507 507 507	485 499 499 485
2 SEMI & DUPLEX	371 400 400 371	371 400 400 371	361 361 361 361	346 356 356 346
3 ROW	254 274 274 254	254 274 274 254	248 248 248 248	239 246 246 239
4 APARTMENT	134 146 146 134	134 146 146 134	131 131 131 131	125 130 130 125

TABLE 7
TEMPERATURE RISES FROM SOLAR GAINS, $\Delta TSOL_{ij\ell n}$, ^{o}F

Non-Electrically Heated n=1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	3.52	3.63	4.54	3.63	4.81	4.69	5.26	5.01
	3.69	3.34	3.69	4.31	4.77	4.57	5.09	4.99
2 SEMI & DUPLEX	3.38	3.49	4.23	3.49	4.48	4.37	4.87	4.66
	3.55	3.21	3.55	4.02	4.44	4.26	4.74	4.63
3 ROW	3.86	3.99	4.57	3.99	4.83	4.72	5.21	5.01
	4.06	3.67	4.06	4.34	4.80	4.59	5.09	4.95
4 APARTMENT	2.80	2.89	3.12	2.89	3.31	3.22	3.59	3.43
	2.94	2.66	2.94	2.96	3.28	3.15	3.48	3.41

Electrically Heated n=2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	5.39	5.17	5.39	5.17	5.55	5.73	5.80	5.82
	5.25	5.12	5.25	5.12	5.83	5.27	5.92	5.51
2 SEMI & DUPLEX	5.10	4.89	5.10	4.89	5.25	5.42	5.47	5.49
	4.97	4.85	4.97	4.85	5.51	4.98	5.58	5.20
3 ROW	5.63	5.40	5.63	5.40	5.77	5.96	5.99	6.01
	5.49	5.35	5.49	5.35	6.06	5.48	6.11	5.69
4 APARTMENT	4.03	3.81	4.03	3.81	4.12	4.26	4.30	4.27
	3.87	3.83	3.87	3.83	4.33	3.92	4.34	4.08

TABLE 8
TEMPERATURE RISES FROM WILD HEAT, $\Delta TAPP_{ij\ell n}$, ^{o}F

Non-Electrically Heated, n=1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	4.00	4.00	5.16	4.00	5.47	5.16	5.98	5.52
	4.00	4.00	4.00	5.16	5.16	5.47	5.52	5.98
2 SEMI & DUPLEX	5.72	5.72	7.16	5.72	7.57	7.16	8.24	7.63
	5.72	5.72	5.72	7.16	7.16	7.57	7.63	8.24
3 ROW	8.63	8.63	10.2	8.63	10.8	10.2	11.6	10.8
	8.63	8.63	8.63	10.2	10.2	10.8	10.8	11.6
4 APARTMENT	14.1	14.1	15.7	14.1	16.7	15.7	18.1	16.7
	14.1	14.1	14.1	15.7	15.7	16.7	16.7	18.1

Electrically Heated, n=2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	6.13	5.69	6.13	5.69	6.31	6.31	6.60	6.41
	5.69	6.13	5.69	6.13	6.31	6.31	6.41	6.60
2 SEMI & DUPLEX	8.62	8.00	8.62	8.00	8.87	8.87	9.25	8.98
	8.00	8.62	8.00	8.62	8.87	8.87	8.98	9.25
3 ROW	12.6	11.7	12.6	11.7	12.9	12.9	13.4	13.0
	11.7	12.6	11.7	12.6	12.9	12.9	13.0	13.4
4 APARTMENT	20.3	18.6	20.3	18.6	20.8	20.8	21.7	20.9
	18.6	20.3	18.6	20.3	20.8	20.8	20.9	21.7

TABLE 9
BALANCE TEMPERATURES, $T^*_{ij\ell n}$, $^{\circ}F$

Non-Electrically Heated, n=1

j / i	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	64.5	64.4	62.3	64.4	61.7	62.1	60.8	61.5
	64.3	64.7	64.3	62.5	62.1	62.0	61.4	61.0
2 SEMI & DUPLEX	62.9	62.8	60.6	62.8	59.9	60.5	58.9	59.7
	62.7	63.1	62.7	60.8	60.4	60.2	59.6	59.1
3 ROW	59.5	59.4	57.2	59.4	56.4	57.1	55.2	56.2
	59.3	59.7	59.3	57.4	57.0	56.6	56.1	55.4
4 APARTMENT	55.1	55.0	53.1	55.0	52.0	53.0	50.3	51.8
	55.0	55.2	55.0	53.3	53.0	52.1	51.8	50.5

Electrically Heated, n=2

j / i	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	60.5	61.1	60.5	61.1	60.1	60.0	59.6	59.8
	61.1	60.7	61.1	60.7	59.9	60.4	59.7	59.9
2 SEMI & DUPLEX	58.3	59.1	58.3	59.1	57.9	57.7	57.3	57.5
	59.0	58.5	59.0	58.5	57.6	58.1	57.4	57.6
3 ROW	53.8	54.9	53.8	54.9	53.3	53.2	52.6	53.0
	54.8	54.1	54.8	54.1	53.1	53.6	52.9	52.9
4 APARTMENT	47.6	49.6	47.6	49.6	47.1	46.9	46.0	46.8
	49.5	47.8	49.5	47.8	46.9	47.3	46.8	46.2

TABLE 10
EQUIVALENT DEGREE-DAYS, $EDD_{ij\ell n}$, ^{o}F
Non-Electrically Heated, n=1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	8430	6410	7810	6410	7660	5820	7400	5650
	6350	10400	6350	9610	5760	9400	5580	9070
2 SEMI & DUPLEX	7980	5990	7360	5990	7190	5400	6920	5210
	5930	9810	5930	9010	5330	8790	5140	8460
3 ROW	7080	5130	6500	5130	6300	4590	6000	4390
	5070	8640	5070	7950	4520	7710	4310	7360
4 APARTMENT	5990	4130	5530	4130	5270	3710	4900	3470
	4060	7310	4060	6780	3640	6470	3400	6050

Electrically Heated, n=2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	7330	5570	7330	5570	7240	5270	7100	5230
	5500	8980	5500	8980	5200	8870	5150	8700
2 SEMI & DUPLEX	6760	5070	6760	5070	6660	4740	6510	4700
	5000	8270	5000	8270	4670	8160	4620	7980
3 ROW	5680	4110	5680	4110	5580	3740	5410	3700
	4040	6990	4040	6990	3660	6870	3630	6680
4 APARTMENT	4340	3030	4340	3030	4230	2540	4020	2520
	2960	5400	2960	5400	2470	5270	2450	5020

TABLE 11

OUTPUT ENERGY REQUIRED FOR SPACE HEATING, $OH_{ij\ell n}$

MMBtu/dwelling yr. Non-Electrically Heated, n=1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	162	123	116	123	108	86.6	95.1	78.7
	122	199	122	143	85.6	132	77.7	117
2 SEMI & DUPLEX	107	80.5	79	80.5	72.9	58.0	64.5	52.5
	79.7	132	79.7	96.7	57.3	89.1	51.8	78.9
3 ROW	63.0	45.7	48.9	45.7	44.9	34.5	39.6	31.1
	45.1	76.9	45.1	59.8	34.0	54.9	30.6	48.6
4 APARTMENT	27.7	19.1	22.9	19.1	20.6	15.4	17.7	13.5
	18.8	33.8	18.8	28.1	15.1	25.3	13.2	21.8

Electrically Heated, n=2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	91.8	75.2	91.8	75.2	88.1	64.2	82.6	62.6
	74.2	112	74.2	112	63.3	108	61.8	101
2 SEMI & DUPLEX	60.2	48.6	60.2	48.6	57.7	41.0	54.1	40.1
	47.9	73.7	47.9	73.7	40.4	70.7	39.5	66.3
3 ROW	34.7	27.1	34.7	27.1	33.3	22.3	31.1	21.9
	26.6	42.7	26.6	42.7	21.8	40.9	21.4	38.3
4 APARTMENT	13.9	10.6	13.9	10.6	13.3	7.97	12.1	7.89
	10.4	17.3	10.4	17.3	7.75	16.5	7.67	15.1

TABLE 12

HEATING VALUES OF THE VARIOUS FUELS USED IN DOMESTIC FURNACES IN CANADA

Fuel	Heating Value
Light Fuel Oil	166,500 Btu/gal
Natural Gas	1,000,000 Btu/thousand ft^3
Liquified Petroleum Gas	117,000 Btu/gal
Electricity	3,412 Btu/kWh

Source: Reference [36].

TABLE 13

TYPICAL SEASONAL EFFICIENCIES FOR NORTH AMERICAN FOSSIL FUEL-FIRED FURNACES

REFERENCE	SEASONAL EFFICIENCY		METHODOLOGY FOR THE DERIVATION OF RESULTS
	OIL FURNACE	GAS FURNACE	
Manian & Juchymenko [28]	60 - 70	60 - 70	Based on the comparison of electrical dwelling to fossil fuel-heated dwelling, adjusted for differences in insulation level (Tests in 4 major Ontario cities: 315 dwellings, all less than 10 years old).
Dunning [34]		65 - 75	Quoting U.S. gas furnace promoters.
Dunning [34]	35 - 45	40 - 50	Gas results based on a single test (USA) measuring actual consumption. Heat loss calculated using adjusted degree day method. Oil result: speculative
Severns & Fellons [46]	65 - 80	75 - 80	No methods described.
Delene & Gaston [29]		50 - 60 (with properly sized furnaces)	Based on 4 tests of actual gas furnace operation in USA. Measurement of fuel consumption and hour-by-hour heat loss was calculated.

TABLE 14

SENSITIVITY OF FURNACE EFFICIENCIES
TO IMPROVED INSULATION LEVELS

Ottawa region, non-electrically heated, single-detached dwelling. Comparison assumes constant furnace capacity.

	Insulation Standards 1966-70	Insulation Standards 1971-75		% change
Heat loss factor, Btu/yr ^{o}F	630.		595.0	-5.5
Heat required, 10^6 Btu/yr	104.1		95.8	-8.2
Ratio of actual furnace capacity to design capacity	1.0		1.058	+5.8
Seasonal furnace efficiency	60%	Gas	59.5	- .5
		Oil	59.1	-1.5
Input heat requirement, 10^6 Btu/yr	174.	Gas	161.	-7.5
		Oil	162.	-6.9

Thus, a planned energy saving of 8.2% would result in an actual saving of 7.5% (gas) and 6.9% (oil) due to the decrease in furnace seasonal efficiency.

TABLE 15

ESTIMATED EFFECT OF CONSERVATION
MEASURES ON FOSSIL FURNACE EFFICIENCIES

	Estimated Efficiencies % * OIL and GAS	
	Steady State	Seasonal
Present Ontario Average	65 - 70	60 - 65
With Proper Maintenance and Servicing	70 - 75	65 - 70
With Hardware Improvements	∿75	∿70
With Positive Chimney Damper	∿75	∿75

* Each successive modification includes the effects of all previous modifications.

TABLE 16

INPUT ENERGY REQUIRED FOR SPACE HEATING, $IH_{ij\ell n}$, MMBtu/dwelling yr

Non-Electrically Heated, n = 1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	270	205	179	189	165	133	146	121
	203	332	188	220	132	203	120	179
2 SEMI & DUPLEX	179	134	122	124	112	89.2	99.2	80.8
	133	220	123	149	88.1	137	79.7	121
3 ROW	105	76.2	75.2	70.3	69.0	53.1	61.0	47.8
	75.2	128	69.4	92.0	52.3	84.5	47.0	74.8
4 APARTMENT	36.9	25.5	30.6	25.5	27.5	20.5	23.6	18.0
	25.1	45.1	25.1	37.5	20.1	33.7	17.7	29.0

Electrically Heated, n = 2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	96.6	79.1	96.6	79.1	92.7	67.5	86.9	65.9
	78.1	118	78.1	118	66.6	114	65.0	107
2 SEMI & DUPLEX	63.4	51.2	63.4	51.2	60.8	43.2	56.9	42.3
	50.5	77.6	50.5	77.6	42.5	74.4	41.6	69.7
3 ROW	36.5	28.5	36.5	28.5	35.0	23.4	32.5	23.0
	28.0	44.9	28.0	44.9	23.0	43.1	22.5	40.3
4 APARTMENT	14.7	11.2	14.7	11.2	14.0	8.39	12.7	8.3
	10.9	18.2	10.9	18.2	8.16	17.4	8.07	15.9

TABLE 17

FUEL CONSUMPTION FOR SPACE HEATING, $FCONH_{ij\ell n}$

Oil Heated, Gallons/dwelling yr.

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	1630	1240	1080	1140	1000	805	884	731
	1230	2010	1130	1330	796	1230	722	1080
2 SEMI & DUPLEX	1080	810	735	748	678	539	600	488
	802	1330	741	898	532	829	482	733
3 ROW	634	460	454	425	417	321	369	289
	454	774	419	556	316	511	284	452
4 APARTMENT	223	154	185	154	166	124	142	109
	152	272	152	226	122	204	107	176

Gas Heated, MCF/dwelling yr.

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	270	205	179	189	165	133	146	121
	203	332	188	220	132	203	120	179
2 SEMI & DUPLEX	179	134	122	124	112	89.2	99.2	80.8
	133	220	123	149	88.1	137	79.7	121
3 ROW	105	76.2	75.2	70.3	69.0	53.1	61.0	47.8
	75.2	128	69.4	92.0	52.3	84.5	47.0	74.8
4 APARTMENT	36.9	25.5	30.6	25.5	27.5	20.5	23.6	18.0
	25.1	45.1	25.1	37.5	20.1	33.7	17.7	29.0

TABLE 17 (CONT'D)
Electrically Heated, 10^3 kWh/Dwelling yr.

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACHED	28.3	23.2	28.3	23.2	27.2	19.8	25.5	19.3
	22.9	34.7	22.9	34.7	19.5	33.3	19.0	31.2
2 SEMI & DUPLEX	18.6	15.0	18.6	15.0	17.8	12.7	16.7	12.4
	14.8	22.7	14.8	22.7	12.5	21.8	12.2	20.4
3 ROW	10.7	8.35	10.7	8.35	10.3	6.87	9.58	6.75
	8.19	13.2	8.19	13.2	6.73	12.6	6.61	11.8
4 APARTMENT	4.29	3.28	4.29	3.28	4.09	2.46	3.73	2.43
	3.21	5.34	3.21	5.34	2.39	5.10	2.37	4.66

TABLE 18
HOT WATER CONSUMPTION, W_i, lb_M/hr

Non-Electrically Heated, n=1

j / i	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	17.49	17.49	17.49	17.49
2 SEMI & DUPLEX	18.44	18.44	18.44	18.44
3 ROW	12.71	12.71	12.71	12.71
4 APARTMENT	10.98	10.98	10.98	10.98

Electrically Heated, n=2

j / i	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	17.49	17.49	17.49	17.49
2 SEMI & DUPLEX	18.44	18.44	18.44	18.44
3 ROW	12.71	12.71	12.71	12.71
4 APARTMENT	10.98	10.98	10.98	10.98

TABLE 19

OUTPUT ENERGY REQUIRED FOR HOT WATER HEATING, OW_i MMBtu/dwelling yr.

Non-Electrically Heated, n=1

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	14.56	same as	pre-1966	figures
2 SEMI & DUPLEX	15.35	same as	pre-1966	figures
3 ROW	10.58	same as	pre-1966	figures
4 APARTMENT	9.14	same as	pre-1966	figures

Electrically Heated, n=2

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	14.56	same as	pre-1966	figures
2 SEMI & DUPLEX	15.35	same as	pre-1966	figures
3 ROW	10.58	same as	pre-1966	figures
4 APARTMENT	9.14	same as	pre-1966	figures

TABLE 20

POTENTIAL FOR IMPROVEMENTS IN WATER HEATING EFFICIENCY

	HOUSEHOLD WATER HEATING EFFICIENCY		
	Electricity	Gas	Oil
Present Values	75%	45%	45%
Estimated Potential Values	80% (90%, Ontario Hydro [4])	60%	60%

TABLE 21

INPUT ENERGY REQUIRED FOR WATER HEATING, IW_{ijn}, MMBtu/dwelling yr

Oil Heating

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	32.4	32.4	32.4	24.3
2 SEMI & DUPLEX	34.1	34.1	34.1	25.6
3 ROW	23.5	23.5	23.5	17.6
4 APARTMENT	12.2	12.2	12.2	12.2

Gas Heating

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	32.4	32.4	32.4	24.3
2 SEMI & DUPLEX	34.1	34.1	34.1	25.6
3 ROW	23.5	23.5	23.5	17.6
4 APARTMENT	12.2	12.2	12.2	12.2

TABLE 21 (CONT'D)

Electrical Heating

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	19.4	19.4	19.4	18.2
2 SEMI & DUPLEX	20.5	20.5	20.5	19.2
3 ROW	14.1	14.1	14.1	13.2
4 APARTMENT	9.62	9.62	9.62	9.62

TABLE 22
FUEL CONSUMPTION FOR WATER HEATING, $FCONW_{ijn}$

Oil Heating, gallons/yr.

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	195	195	195	147
2 SEMI & DUPLEX	206	206	206	155
3 ROW	142	142	142	107
4 APARTMENT	73.6	73.6	73.6	73.6

Gas Heating, MCF/yr

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	32.4	32.4	32.4	24.3
2 SEMI & DUPLEX	34.1	34.1	34.1	25.6
3 ROW	23.5	23.5	23.5	17.6
4 APARTMENT	12.2	12.2	12.2	12.2

TABLE 22 (CONT'D)

Electrical Heating, 10^3 kWh/yr

i \ j	1 PRE 1966	2 1966 - 70	3 1971 - 75	4 POST 1975
1 SINGLE DETACHED	5.7	5.7	5.7	5.3
2 SEMI & DUPLEX	6.0	6.0	6.0	5.6
3 ROW	4.1	4.1	4.1	3.9
4 APARTMENT	2.8	2.8	2.8	2.8

TABLE 23

ONTARIO WATER HEATER CHARACTERISTICS, 1974

	WATER HEATER FUEL		
	Electricity	Gas	Oil
Output per household, 10^6 Btu/year	13.8	13.8	13.8
Saturation, %	54	35 (est)	5 (est)
Efficiency, %	75	45	45
Energy required per household, 10^6 Btu/year	9.94	10.73	1.53
Number of Households in Ontario	2,453,000		
Total Energy Use 10^{12}Btu/year	24.4	26.3	3.75

TABLE 24

POWER REQUIRED FOR SPACE COOLING, $ROHA_{ij\ell n}$, MBtu/hr.

Non-Electrically Heated

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	16.7	16.7	13.5	15.5	12.6	13.5	11.3	12.6
	18.6	13.6	17.4	11.5	15.0	10.7	13.9	9.65
2 SEMI & DUPLEX	12.0	12.0	9.82	11.1	9.2	9.82	8.25	9.1
	13.4	9.8	12.5	8.32	11.0	7.8	10.2	6.99
3 ROW	8.7	8.7	7.32	8.13	6.9	7.32	6.2	6.86
	9.7	7.23	9.10	6.2	8.17	5.8	7.65	5.3
4 APART.	5.1	5.1	4.3	4.72	3.98	4.26	3.6	3.98
	5.7	4.3	5.3	3.55	4.8	3.31	4.5	2.9

Electrically Heated

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	11.5	12.9	11.5	12.9	11.3	11.3	10.7	11.3
	14.3	9.82	14.3	9.82	12.5	9.7	12.5	9.1
2 SEMI & DUPLEX	8.4	9.35	8.41	9.35	8.25	8.25	7.84	8.23
	10.4	7.1	10.4	7.1	9.20	7.0	9.2	6.6
3 ROW	6.35	7.00	6.35	7.00	6.25	6.25	5.96	6.24
	7.8	5.4	7.81	5.4	6.97	5.3	6.96	5.0
4 APART.	3.62	4.05	3.62	4.05	3.6	3.57	3.4	3.56
	4.56	2.99	4.56	2.99	4.02	2.95	4.02	2.78

TABLE 25

OUTPUT ENERGY REQUIRED FOR SPACE COOLING, $OHA_{ij\ell n}$, MMBtu/dwelling yr.

Non-Electrically Heated

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	8.0	8.0	6.5	7.44	6.0	6.5	5.4	6.03
	8.9	6.5	8.3	5.5	7.2	5.15	6.7	4.63
2 SEMI & DUPLEX	5.7	5.7	4.7	5.34	4.4	4.72	3.95	4.39
	6.4	4.7	6.0	3.99	5.3	3.72	4.9	3.35
3 ROW	4.2	4.2	3.5	3.9	3.3	3.5	2.99	3.3
	4.7	3.5	4.4	2.97	3.9	2.79	3.7	2.53
4 APART.	2.4	2.4	2.05	2.3	1.91	2.0	1.71	1.91
	2.7	2.0	2.55	1.70	2.3	1.59	2.15	1.42

Electrically Heated

i \ j	2 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH	5.5	6.2	5.5	6.2	5.4	5.4	5.1	5.4
	6.8	4.7	6.8	4.7	6.0	4.6	6.0	4.4
2 SEMI & DUPLEX	4.0	4.5	4.0	4.5	4.0	4.0	3.8	4.0
	5.0	3.4	5.0	3.4	4.4	3.4	4.4	3.2
3 ROW	3.0	3.4	3.0	3.4	3.0	3.0	2.9	3.0
	3.7	2.6	3.7	2.6	3.3	2.5	3.3	2.4
4 APART	1.7	1.9	1.7	1.9	1.7	1.7	1.6	1.7
	2.2	1.4	2.2	1.4	1.9	1.4	1.9	1.3

TABLE 26

ELECTRICAL EFFICIENCY RATIOS FOR AIR CONDITIONING UNITS

Type of Unit	EER Btu/Watt hr	Coefficient of Performance
Typical Central Air Conditioning Unit	8.0 - 10.0	2.34 - 2.92
Typical Room Air Conditioner	6.5 - 7.0	1.90 - 2.05
"Oversized" room Air Conditioners	9. - 12.	2.64 - 3.52

TABLE 27

INPUT ENERGY REQUIRED FOR SPACE COOLING, $IHA_{ij\ell n}$, MMBtu/dwelling yr.

Non-Electrically Heated

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	3.4	3.4	2.77	3.18	2.58	2.77	2.05	2.28
	3.8	2.8	3.56	2.37	3.08	2.20	2.53	1.75
2 SEMI & DUPLEX	2.45	2.45	2.02	2.28	1.88	2.02	1.50	1.66
	2.7	2.0	2.56	1.71	2.25	1.59	1.85	1.27
3 ROW	1.8	1.79	1.5	1.67	1.41	1.50	1.13	1.25
	1.99	1.5	1.87	1.27	1.68	1.19	1.39	.98
4 APART.	1.0	1.0	.874	.967	.816	.874	.648	.723
	1.2	.87	1.09	.728	.984	.679	.814	.537

Electrically Heated

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	2.36	2.64	2.36	2.64	2.32	2.32	1.95	2.05
	2.93	2.02	2.93	2.02	2.57	1.98	2.27	1.66
2 SEMI & DUPLEX	1.73	1.92	1.73	1.92	1.69	1.69	1.43	1.50
	2.14	1.46	2.14	1.46	1.89	1.44	1.67	1.21
3 ROW	1.30	1.43	1.30	1.43	1.28	1.28	1.08	1.13
	1.6	1.10	1.6	1.1	1.43	1.08	1.7	.915
4 APART.	.742	.83	.742	.83	.731	.73	.613	.65
	.935	.614	.935	.614	.825	.606	.731	.506

TABLE 28

FUEL CONSUMPTION FOR SPACE COOLING, $FCONHA_{ij\ell n}$, kWh/dwelling yr.

Non-Electrically Heated, n=1

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	1000	1000	813	931	756	813	600	669
	1120	820	1040	693	902	645	742	514
2 SEMI & DUPLEX	718	718	590	669	550	590	439	487
	805	589	751	500	658	466	542	372
3 ROW	523	523	440	489	413	440	332	366
	584	439	547	372	491	349	407	281
4 APART.	307	307	256	283	239	256	190	212
	344	256	319	213	288	199	238	157

Electrically Heated, n=2

i \ j	1 PRE 1966		2 1966 - 70		3 1971 - 75		4 POST 1975	
1 SINGLE DETACH.	693	773	693	773	679	679	570	600
	858	590	858	590	753	581	665	487
2 SEMI & DUPLEX	505	562	505	562	496	496	418	439
	626	427	626	427	553	420	488	353
3 ROW	381	420	381	420	375	375	318	332
	469	322	469	322	419	318	371	268
4 APART.	218	243	218	243	214	214	180	190
	274	180	274	180	242	178	214	148

TABLE 29

ENERGY UTILIZATION CHARACTERISTICS
OF MAJOR APPLIANCES - 1974

APPLIANCE	AVERAGE POWER (WATTS)	AVERAGE UTILIZATION FACTOR	YEARLY ENERGY CONSUMPTION KWH/YEAR	SATURATION OF ELECTRICAL APPLIANCES (%)	AVERAGE CONSUMPTION PER HOUSEHOLD KWH/YEAR
Lighting			758	100	758
Refrigerators	300	.38	1,000	99.4	994
Cooking Range	12,500	.011	1,220	86.3	1,052
B & W TV	200	.200	350	72.7	254
Color TV	330	.190	550	46.3	255
Clothes Washers	500	.022	96	45.0	43
Clothes Dryer	4,800	.023	960	43.0	413
Freezer	335	.307	900	38.8	349
Air Conditioner	1,200	.057	600	17.1	103
Dishwasher	1,300	.019	216	15.5	34
Miscellaneous (See TABLE 36)			2,386	27.8 (average)	663
					4,920

TABLE 30

SATURATION OF APPLIANCES BY FUEL TYPE - 1974

Class	Saturation, %		
	Electricity	Gas	Other
a) Appliances With 100% Penetration			
Lighting	100		
Cooking equipment	86	14	
Refrigerators, freezers	100		
Radio, TV	100		
b) Appliances With Less Than 100% Penetration			
Clothes washers	75		
Clothes dryers	43	6.4	
Dishwashers	16		
Room air-conditioners	19*		
c) Others	60		

* 19% of the total number of houses not having central air conditioning.

TABLE 31

APPLIANCE ENERGY REQUIRED PER HOUSEHOLD YEAR, 1974

Weighted according to Saturation

Class	Energy Requirement (10^6 Btu/yr) Electricity		Gas	Other
a) Appliances With 100% Penetration				
Lighting	2.59	12.8	0.820	
Cooking equipment	3.53			
Refrigerators, freezers	4.63			
Radio, TV	2.05			
b) Appliances With Less Than 100% Penetration				
Clothes washers	0.210	2.12	0.226	
Clothes dryers	1.410			
Dish washers	0.114			
Room air-conditioners	0.389			
c) Others	1.88			
Total/household	16.8		0.784	
Number of households, 1974	2,453,000			
Total Energy Requirements, 10^{12} Btu/yr	41.2		1.92	

TABLE 32

APPLIANCE EFFICIENCIES BY FUEL TYPE, 1974

Class	Efficiency Factor, %		
	Electricity	Gas	Other
a) Appliances With 100% Penetration			
Lighting	5		
Cooking equipment	45	35	
Refrigerators, freezers	100*		
Radio, TV	100*		
b) Appliances With Less Than 100% Penetration			
Clothes washers	100*		
Clothes dryers	40	37	
Dishwashers	100*		
Room air-conditioners	100*		
c) Others	100*		100*

* An efficiency of 100% denotes that the efficiency is not known, has not yet been established or is not meaningful.

TABLE 33

OUTPUT ENERGY REQUIRED PER APPLIANCE YEAR, 1974

Class	Output 10^6 Btu/year Appliance-Year	Output 10^6 Btu/year Class-Year
a) Appliances With 100% Penetration		
Lighting	0.129	
Cooking equipment	1.88*	8.69
Refrigerators, freezers	4.63	
Radio, TV	2.05	
b) Appliances With Less Than 100% Penetration		
Clothes washers	0.280	
Clothes dryers	1.31	4.43
Dishwashers	0.737	
Room air-conditioners	2.05	
c) Others	3.07	3.07

* Weighted average from Tables 31 and 32.

TABLE 34

POTENTIAL FUEL SAVING FOR MAJOR APPLIANCES

Appliance	FEA*	Commerce**
Refrigerators	43-50%	30%
Freezers	33-40%	25%
Dishwashers	22-40%	18%
Gas clothes dryers	14-20%	12%
Electric clothes dryers	6-14%	6%
Black and white TV's	92-94%	48%
Color TV's	50-80%	42%
Electric ranges	8-20%	10%
Gas ranges	43-50%	30%
Clothes washers	11-50%	10%
Room air conditioners	28-40%	22%

* U.S. Federal Energy Administration

** U.S. Department of Commerce

Source: Reference [41].

TABLE 35

POTENTIAL IMPROVEMENTS*IN EFFICIENCY FACTORS**
OF APPLIANCES

Class	Projected Efficiency Factors, % Electric	Gas
a) Appliances With 100% Penetration		
Lighting	5	
Cooking equipment	55	70
Refrigerators, freezers	140	
Radio, TV	181	
b) Appliances With Less Than 100% Penetration		
Clothes washers	110	
Clothes dryers	43	45
Dishwashers	115	
Room air-conditioners	130	
c) Others	125	
Reduction in appliance energy demand	20%	

* The present plans for energy conservation are almost "step-function" in nature. Extensive research and development at present is to improve efficiencies as soon as possible. If goals are reached, there will be little scope for improvement after the near-term.

** Efficiency Factor is defined as the efficiency that would produce a specified fuel saving relative to the base period efficiencies (Table 32).

TABLE 36

ENERGY CHARACTERISTICS OF
MISCELLANEOUS HOUSEHOLD APPLIANCES
IN ONTARIO, 1974

Appliance	Power, watts	Approximate Energy Use, kWh/year
Dehumidifier	250	180
Iron	1,000	144
Kettle	1,500	144
Humidifier (portable)	100	120
Hi-fi (tube)	115	120
Hi-fi (solid state)	30	72
Electric Blanket	180	120
Broiler	1,400	120
Block Heater	500	120
Hot Plate	1,320	96
Radio (tube)	50	96
Deep Fat Fryer	1,500	84
Coffee Maker	900	72
Vacuum Cleaner	800	48
Fan (portable)	115	48
Self-cleaning Cycle of Range	3,200	48
Food Waste Disposer	450	36
Toaster	1,150	36
Lawn Mower	1,500	12
Grill (sandwich)	1,160	36
Hair Dryer	350	36
Rotisserie	1,400	24
Waffle Iron	1,120	24
Foodmixer	125	24
Barbeque Grill	1,350	15
Tooth Brush	10	12
Can Opener	175	12
Knife (carving)	92	12
Clock	2	12
Drill	300	2
Floor Polisher	300	12
Food Blender	390	12
Heat Lamp	250	6
Heating Pad	65	12
Hedge Trimmer	25	2
Power Saw	275	2
Radio (solid state)	5	12
Sewing Machine	75	12
Shaver	15	12
Sun Lamp	280	6

Source: Reference [24].